ce Library
JAN 31 1947

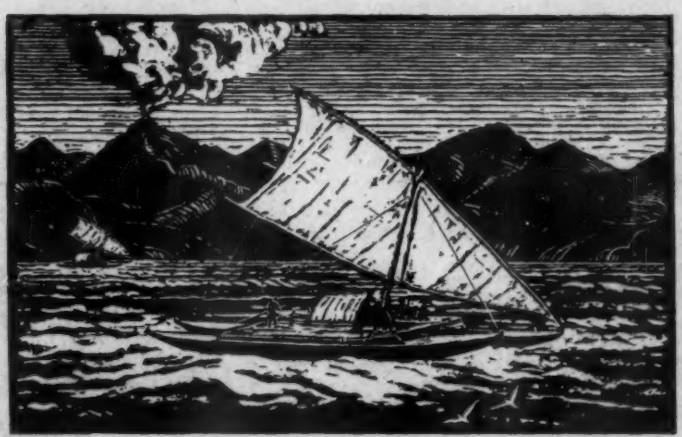
VOL. I JANUARY, 1947 No. 1

EXCHANGE COPY

# PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

79



IN THIS ISSUE: St. John—*Sandalwood on Oahu, Hawaiian Islands* • Macdonald, Shepard, and Cox — *Tsunami of April 1, 1946, in the Hawaiian Islands* • Sherman, Kanehiro, and Fujimoto—*Dolomitization in Semi-Arid Hawaiian Soils* • Fisher and Baldwin — *The Red-Billed Leiothrix in Hawaii* • NOTES

*Published by*
THE UNIVERSITY OF HAWAII
HONOLULU, HAWAII

# BOARD OF EDITORS

A. GROVE DAY, *Editor-in-Chief*, Department of English, University of Hawaii

ERVIN H. BRAMHALL, Department of Physics, University of Hawaii

VERNON E. BROCK, Director, Division of Fish and Game, Territorial Board of Agriculture and Forestry

HARRY F. CLEMENTS, Plant Physiologist, University of Hawaii Agricultural Experiment Station

ROBERT B. DEAN, Department of Chemistry, University of Hawaii

CHARLES H. EDMONDSON, Zoologist, Bishop Museum, Honolulu, T. H.

HARVEY I. FISHER, Department of Zoology, University of Hawaii

FREDERICK G. HOLDAWAY, Head, Department of Entomology, University of Hawaii Agricultural Experiment Station

MAURICE B. LINFORD, Head, Department of Plant Pathology, Pineapple Research Institute, Honolulu, T. H.

A. J. MANGELSDORF, Geneticist, Experiment Station, Hawaiian Sugar Planters' Association, Honolulu, T. H.

HAROLD ST. JOHN, Chairman, Department of Botany, University of Hawaii

CHESTER K. WENTWORTH, Geologist, Honolulu Board of Water Supply


# SUGGESTIONS TO AUTHORS

Contributions to Pacific biological and physical science will be welcomed from authors in all parts of the world. Manuscripts should be addressed to Dr. A. Grove Day, Editor, PACIFIC SCIENCE, University of Hawaii, Honolulu 10, Hawaii. Use of air mail for sending correspondence and brief manuscripts from distant points is recommended. Manuscripts will be read promptly by members of the Board of Editors and by other competent critics.

Manuscripts may run from 1 to 30 pages in length. Authors should not overlook the need for good brief papers presenting results of studies, notes and queries, communications to the editor, or other commentary.

## PREPARATION OF MANUSCRIPT

Although no manuscript will be rejected merely because it does not conform to the style of PACIFIC SCIENCE, it is suggested that authors follow the style recommended below and exemplified in the journal.

*Title.* Titles should be descriptive but brief. If a title runs to more than 40 characters, the author should also supply a "short title" for use as a running head.

*Manuscript form.* Manuscripts should be typed on one side of standard-size, white bond paper and double-spaced throughout. Pages should be consecutively numbered in upper right-hand corner. Sheets should not be fastened together in any way, and should be mailed flat. Inserts should be either typed on separate sheets or pasted on proper page, and point of insertion should be clearly indicated.

*Original copy and one carbon copy* of manuscript should be submitted. The author should retain a carbon copy. Although due care will be taken, the editors cannot be responsible for loss of manuscripts.

*Introduction and summary.* It is desirable to state the purpose and scope of the paper in an introductory paragraph and to give a summary of results at the end of the paper.

*Dictionary style.* It is recommended that authors follow capitalization, spelling, compoundings abbreviations, etc., given in *Webster's New International Dictionary* (unabridged), second edition; or, if desired, the *Oxford Dictionary*. Abbreviations of titles of publications should, if possible, follow those given in U. S. Department of Agriculture Miscellaneous Publication 337.

*Footnotes.* Footnotes should be used sparingly and never for citing references (see later). Often, footnotes may better be incorporated into the text or omitted. When used, footnotes should be consecutively numbered by superior figures through-

[*Continued on inside back cover*]

# PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

VOL. I JANUARY, 1947 No. 1

*Issue printed December 10, 1946*

## CONTENTS

PAGE

*The History, Present Distribution, and Abundance of Sandalwood on Oahu, Hawaiian Islands.* HAROLD ST. JOHN . . . . . 5

*The Tsunami of April 1, 1946, in the Hawaiian Islands.* G. A. MACDONALD, F. P. SHEPARD, AND D. C. COX . . . . . 21

*Dolomitization in Semi-arid Hawaiian Soils.* G. DONALD SHERMAN, YOSHINORI KANEHIRO, AND CHARLES K. FUJIMOTO . . . . . 38

*Notes on the Red-billed Leiothrix in Hawaii.* HARVEY I. FISHER AND PAUL H. BALDWIN . . . . . 45

NOTES:

*Recommendations of Pacific Science Conference, National Research Council* . 52

*Micronesian Expedition of University of Hawaii, Summer of 1946* . . . 60

*Survey of Micronesia by U.S. Commercial Company, 1946* . . . . . 62

*Cover drawing by A. S. MacLeod*

PACIFIC SCIENCE, a quarterly publication of the University of Hawaii, appears in January, April, July, and October. Subscription price is three dollars a year; single copies are one dollar. Check or money order payable to University of Hawaii should be sent to PACIFIC SCIENCE, Office of Publications, University of Hawaii, Honolulu 10, Hawaii.

Science Library

Science Library
Q
1
.P12

Science Library
Lyon
Library
University of Hawaii
1-20 47

# The History, Present Distribution, and Abundance of Sandalwood on Oahu, Hawaiian Islands: Hawaiian Plant Studies 14[1]

HAROLD ST. JOHN[2]

## INTRODUCTION

TODAY IT IS a common belief of the residents of the Hawaiian Islands that the sandalwood tree was exterminated during the sandalwood trade in the early part of the nineteenth century and that it is now extinct on the islands. To correct this impression, the following notes are presented.

There is a popular as well as a scientific interest in the sandalwood tree or iliahi of the Hawaiians, the fragrant wood of which was the first important article of commerce exported from the Hawaiian Islands.

For centuries the sandalwood, with its pleasantly fragrant dried heartwood, was much sought for. In the Orient, particularly in China, Burma, and India, the wood was used for the making of idols and sacred utensils for shrines, choice boxes and carvings, fuel for funeral pyres, and joss sticks to be burnt in temples. The distilled oil was used in numerous medicines, perfumes, and cosmetics, and as a body rub. The thick oil pressed from the seed was used as illuminating oil.

Though long believed to be native to India, the "white sandalwood," *Santalum album* L., the species first commercialized, is now considered to have been introduced into India many centuries ago and cultivated there for its economic and sentimental values. Only in more recent times has it attained wide distribution and great abundance in that country. It is certainly indigenous in Timor and apparently so all along the southern chain of the East Indies to eastern Java, including the islands of Roti, Wetar, Sawoe, Soemba, Bali, and Madoera. The earliest voyagers found it on those islands and it was early an article of export, reaching the markets of China and India (Skottsberg, 1930: 436; Fischer, 1938). The insufficient and diminishing supply of white sandalwood gave it a very high and increasing value. Hence, trade in the wood was profitable even when a long haul was involved.

## THE GENUS *Santalum*

The genus *Santalum* contains several species and most, if not all, of these are acceptable alternatives or substitutes for *S. album*. Hence, each newly discovered stand of any species of sandalwood attained great economic value. There are now 19 accepted species of *Santalum* occurring naturally from Java to Juan Fernandez, Hawaii, and the Bonin Islands. These species are found as follows:

Java to Timor—*S. album* L.

New Guinea—*S. Macgregorii* F. Muell., *S. papuanum* Summerh.

Australia—*S. lanceolatum* R. Br., *S. obtusifolium* R. Br., *S. ovatum* R. Br.

[1] This is the fourteenth of a series of papers designed to present descriptions, revisions, and records of Hawaiian plants. The following papers have been published as Bernice P. Bishop Museum Occasional Papers: 10 (4), 1933; 10 (12), 1934; 11 (14), 1935; 12 (8), 1936; 14 (8), 1938; 15 (1), 1939; 15 (2), 1939; 15 (22), 1940; 15 (28), 1940; 17 (12), 1943; and nos. 11, 12, and 13 are in press.

[2] Chairman, Department of Botany, University of Hawaii.

New Caledonia, Loyalty Islands, New Hebrides—*S. austrocaledonicum* Vieillard

Fiji—*S. Yasi* Seem.

Tahiti, Raiatea, Austral Islands, Rapa, Marquesas—*S. insulare* Bertero

Henderson Island—*S. hendersonense* F. B. H. Br.

Juan Fernandez—*S. fernandezianum* Phil. (now extinct)

Hawaiian Islands—*S. ellipticum* Gaud., *S. Freycinetianum* Gaud., *S. haleakalae* Hbd., *S. lanaiense* Rock, *S. paniculatum* H. & A., *S. Pilgeri* Rock, *S. pyrularium* Gray

Bonin Islands—*S. boninense* (Nakai) Tuyama

## THE SANDALWOOD ERA IN HAWAII

The Hawaiian people were familiar with the pleasant aroma of the iliahi. They called its wood laau ala (or laau aala), meaning "fragrant wood," and they sprinkled finely powdered heartwood on their kapa or bark cloth to perfume it.

Just how the Hawaiian sandalwood trade began is not known. Perhaps the Hawaiians showed the pleasantly scented wood to the white voyager or "haole." Perhaps, as has been suggested, logs of iliahi were included in firewood furnished to sailing vessels in an island port and some sea captain, veteran of the China trade, recognized the sweet perfume of sandalwood oil coming from the burning wood in the cook stove. The actual beginning is not certainly known, but the first record is as follows (Bradley, 1942: 26–27; see Ingraham, 1791: 15, 19, 20, 23, 24):

> The earliest specific mention of sandalwood at the Islands is attributed to Isaac Ridler, a deserter from the "Columbia." Ridler was at Kealakekua Bay in March 1790, during the visit of the "Eleanora"; a year later, he told Captain Joseph Ingraham that while at Kealakekua Captain Metcalfe had engaged in "taking in sandalwood." Metcalfe may have purchased the sandalwood for use as firewood; it is also possible, if we may credit Ridler's testimony, that he was the first to carry sandalwood from the Hawaiian Islands to China for commercial purposes.

In 1790, Captain John Kendrick of the "Lady Washington" left two men on Kauai to collect sandalwood for his next return from Boston. Before May, 1791, Captain William Douglas of the "Grace" (Ingraham, 1791: 15, 19) put two men ashore on Kauai to collect sandalwood, "which wood he had discovered or a wood similar to it."

There is doubt about the accuracy of these early records, for Amasa Delano (1817: 399; see Bradley, 1942: 27) observed in 1801 that the first sandalwood shipped from the islands to China was not the real sandalwood and was of such inferior quality that the Chinese merchants refused to purchase it.

From 1790 to 1810 sandalwood may have been exported, but if so, in very small quantity, for little record is found. Then, in 1809, two brothers, the American ship captains Jonathan Winship of the "Albatross" and Nathan Winship of the "O'Cain," started on a voyage that established the sandalwood trade. After trading for furs on the coast of Oregon, they sailed in October, 1811, for Honolulu, where they and Captain William Heath Davis of the "Isabella" took on cargoes of sandalwood. The ships sailed to Canton, where the fragrant wood was sold at a large profit. Returning to Honolulu, the three captains persuaded King Kamehameha I to grant them a monopoly of the sandalwood and cotton trade for 10 years. Loading five ships, the three captains sailed to Canton and thus established a highly remunerative traffic. While they were in China, the startling news came that America and Great Britain were at war, and when the captains returned to Honolulu they found Kamehameha unfriendly. He canceled their trade monopoly and refused to renew it, his changed attitude being due, they reported, to British influence (Davis, 1816: 52–53).

Thereafter, though no longer a trader's monopoly, the sandalwood trade developed rapidly and throve from 1815 to 1826. The successive Hawaiian kings at first followed the example of the shrewd Kamehameha I and kept sandalwood as a royal monopoly,

but later they shared it with the higher chiefs. Taxes, to be paid in sandalwood, were levied on the district chiefs, who in turn levied them on their retainers, the people. Wanting some of the white man's sailing ships, the king bought several, paying for them, it is said, with an equal or a double tonnage of sandalwood. For measuring the amount, a rectangular pit the size of the greatest length, breadth, and depth of the hull was dug, then filled with sandalwood logs (Rock, 1916: 10). These pits are still reported in various parts of the islands, and there is one, identified by the late Albert F. Judd, at about 800 feet elevation on the Kapalama-Nuuanu ridge, on the grounds of the Kamehameha Schools, Honolulu.

After the death of Kamehameha I in 1819, his successors ruled, but without the sagacity and shrewdness of the great king. Their sandalwood monopoly still seemed to them an inexhaustible source of wealth. The wood was marketed in China by the picul (133⅓ pounds) and its value fluctuated from $3.00 to $18.00; during the prosperous years 1825 to 1827 it sold at from $10.50 to $14.00 a picul. In 1822–23 a total of 20,000 piculs was sold in Canton. The trade was a great resource for Kamehameha I, but for the next two kings, Liholiho and Kauikeaouli, and their womenfolk, it was a bonanza. They paid $77,000 for a brig and its cargo. They bought frame houses shipped ready-cut, silks, woolens, liquors, cut glass, and luxuries of many other kinds. They paid $800 for a looking glass and $10,000 for a brass cannon. With the consent of the eager, competing traders, these purchases were accepted on credit for sandalwood to be delivered later. These reckless purchases piled up royal debts in 1821 of 22,000 piculs—or $220,000 calculated at $10 a picul, the quotation for 1821–23 (see Mathison, 1825: 5)—and by 1824 of about $300,000.

Not only were the logs of sandalwood the prime article of commerce, but for some years they served as a medium of exchange in the absence of a local coinage. This fact is recorded by James Hunnewell (1895: 16), who as a ship's officer made several voyages to Hawaii. When, on one of the voyages, the cargo was only partly disposed of by sale, Hunnewell was left in Honolulu with the remaining part of the cargo to sell. He wrote, concerning the years 1817 and 1818:

> Business seems to have been conducted, to a very considerable extent, by barter. Sandal wood was the chief article, indeed it might almost have been called the standard coin, although Spanish silver more nearly reached that definition. There is constant mention of sticks or piculs of the wood, but none of money. May 14th [1818] is a note, "Sold 40 looking glasses for 4 piculs wood"; next day, "Sold the remainder of the muslin, 2 pieces, for 31 piculs wood received." These examples are enough to show the nature of trade.

The king and the chiefs, pressed for payment, put pressure on the people, whose labor made the trade possible and who received little or none of the profit. There are numerous contemporary accounts of the forced gathering of sandalwood. All the inhabitants able to go were ordered into the hills in search of the precious wood. The trees were cut down and chopped into logs 6 to 8 feet long; then with adzes the bark and sapwood were chipped off. Men and women tied the logs to their backs with the fibrous leaves of the ti (*Cordyline terminalis*) and trudged to the measuring pit or to the shore. As many as a dozen small ships were used to haul the logs to Honolulu. Ellis (1826: 275) at Olaa, Hawaii, encountered a chief with about 400 people bearing sandalwood from the mountains. There are also accounts of the gathering of logs by two to three thousand people near Waipio, Hawaii. The following account by a British sailor ("Old Quarter Master," 1839: 220–221) does not seem to have been noticed before, and it is here quoted because of its

charm and because it gives a picture of gathering the wood at night:

January, 1827, weighed and made sail, and after a fine passage anchored within the reefs, at Whahoo [Oahu], where we found an American ship. . . . Sometime before our arrival the Government had purchased a vessel from an American Merchant called the Chinchili; this vessel was to be paid for in sandal wood, which was as usual levied in certain quantities from each of the Chiefs. . . .

The time of cutting it is appointed by the King, and that is invariably at night, but for what cause I could never find out; this time was appointed while we lay here, and the Captain was invited to accompany the young King to view the scene; our cutter was ordered to take the party, and it took us nearly all the forenoon to get to the spot. When the party took horses and left me in charge of the boat, I asked and obtained leave to ascend the hill in the evening; the ascent was painful and fatiguing, but it fully repaid me by the pleasing sight that met my eyes; there stood a vast number of men assembled, each with a torch made from sandal wood, which burns bright and clear, at a certain signal they dispersed; each taking his own way to cut his load, accompanying his labour with a song, to which the whole band within hearing join in chorus; the song we understood not, but in the calm of a beautiful night it was calculated to inspire delight. After the labour of two or three hours the wood is collected together, each Chief inspecting his own lot, judging of the quality by the colour and weight; it is then taken to the water's edge where it is piled end on ready for boats to take away; the people then returned to their homes, and we to the young King's country house, after which I went to the boat.

As the king bought greater and greater quantities of imported goods, his demands for sandalwood in taxes became greater and more frequent. Tax records were kept, some of which are still extant and may be consulted at the Public Archives, Honolulu. The writer studied them carefully in hope of finding exact records, including the localities where sandalwood was cut. The records are few, fragmentary, and difficult to interpret. One of the best is a sheet kept by the Spaniard Francisco de Paula Marin, who was a councilor or business manager of Kamehameha I. The year date is lacking. Each center entry is the name of a district on Oahu or of the chief ruling that district. Then, in three columns appear the day and month, the number of piculs, and the number of pieces, all written in Spanish. In brackets is here suggested the modern spelling or translation, as follows:

SANDALWOOD TAX RECORD FOR OAHU BY DON FRANCISCO MARIN

| | | |
|---|---|---|
| | | Guaguigui [Waikiki] |
| dia | 24 de Septiembre | 240 piculs |
| | 25 | 50 |
| | | Taguipu [Kahuku?] |
| dia | 18 de Septiembre | 168 |
| | | Cayrua [Kailua] |
| | 16 | 1200 |
| | | Guaymanamano [Waimano] |
| | 16 | 1200 10 pedazos [pieces] |
| | | Caneoje [Kaneohe] |
| | 16 | 800 5 |
| | | Teylla [Kealia] |
| | 17 | 1200 |
| | | Cajanu [Kahana?] |
| | 17 | 120 |
| | | Camejameja [Kamehameha, the governor of part of Oahu] |
| | 23 | 4400 |
| | 27 | 1080 |
| | 29 | 230 |
| | | Tonuaunau [unidentified] |
| | 28 | 580 |
| | | Guallanae [Waianae] |
| | 23 | 415 |

Marin's journal, in manuscript translation in the Public Archives, also gives some data on the gathering of sandalwood taxes.

MARIN'S JOURNAL NO. 2

27 Sept. 1811. Marin cutting Wood for King.

26 Dec. 1811. Marin goes to cut Wood with the Minister.

4 Aug. 1812. This day the King made a Contract with Captain Guynan [Winship] and Capt. Debes [Davis] not to sell fragrant wood to anyone but to them.

25–26 Oct. 1814. Kealakekua, Hawaii. Went on shore to see King. Spoke to him about perfumed wood. He gave no answer.

18 Feb. 1818. This day weighing wood—116 piculs.

JOURNAL NO. 4

1 March 1819. Quinopu & Quehomaquea left for Waimea to fetch sandalwood [they were probably tax collectors, now unidentified].

Journal No. 5

2 Dec. 1819. Poqui [Boki] buys boat of Capt. Luis for twice its full of Sanlegue [sandalwood].

19 March 1821. This day Craymoca [Kalanimoku] started to collect sandalwood and Poqui [Boki] for Quallanae [Waianae].

22 Oct. 1821. Pitt [Billy Pitt or Kalanimoku, the king's prime minister and treasurer] bought schooner "Asta" for 1280 Piculs of Sanlegud [sandalwood].

Journal No. 6

15 Jan. 1822. Sandalwood for caulking.

8 Aug. 1822. Embarked sandalwood on ship America.

It will readily be seen that these historic documents are incomplete and lack details as to the exact localities where the sandalwood trees grew.

The tax levies increased, becoming more and more exacting, and as all chroniclers agree, they became an intolerable burden on the people. As the easily accessible sandalwood stands had been felled, the people had to climb farther and farther into the wet, cold mountain forests and the quests were no longer like idyllic song fests. The people were driven to the task, and many died of exposure in the mountains. While they were away in the interior, crops and taro patches were neglected, so that famine came to the islands and took its toll of the king's subjects.

Eventually the shipments decreased and the wood gathered was smaller and of poor quality. In 1828–29, 13,000 piculs of sandalwood were shipped. In 1830–31 the shipments, wholly of small and crooked sticks, brought only $1.50 a picul. This poor yield finished the sandalwood trade in the Hawaiian Islands. Says Mesick (1934: 140):

> A few years later [than 1825], seeing that the supply was rapidly diminishing, the government took steps to conserve it; but despite this tardy measure it is only occasionally that sandalwood trees are found in the Hawaiian forests.

A similar summary (Kuykendall and Gregory, 1926: 116–117) reads:

> The reckless way in which the trees were cut destroyed the forests. Very little effort was made to preserve the young trees or to replace those which were cut down. In a few years sandalwood almost disappeared from the islands. Even to-day, a hundred years after the trade was at its height, only a few small groves are to be found.

These statements emphasize the depletion of the stands of sandalwood, but exaggerate the present scarcity.

## Bennett's Locality for Sandalwood

Since locality records given by the earlier botanists and explorers are few and are often lacking in detail, in general they are not quoted here. However, there is one of real interest. Dr. George Bennett (or Bennet) was a British physician who accompanied the Rev. Daniel Tyerman on a world tour. A detailed and readable report on the Christian missions and also an account of their general observations was edited by James Montgomery (1831). The pair visited many island groups, some very remote. In the decade after their return to England, Bennett published several scientific or botanical accounts; then, after settling in Australia, he continued work in natural history. While in England he published "An account of the sandal wood tree" (1832). A specimen of *Santalum* which he had collected on Oahu was deposited with his other collections in the Botanical Museum at Berlin-Dahlem; no other herbarium seems to have any duplicates of his collections.

Professor J. F. Rock (1916: 19–21) studied this specimen in Berlin and stated in his notes that it agreed perfectly with an authentic Gaudichaud specimen of *S. Freycinetianum* Gaud. The data are: "Santalum, Sandalwood Tree, Native name Iliahi or Lauhala. Wouhala, Oahu, Sandwich Islands, December, 1830. The tree is of slow growth and inhabits elevated and rocky situations.

G. Bennett." Rock's paper is a detailed monograph of the Hawaiian species of *Santalum*. For *S. Freycinetianum* he cites only four collections from three localities: "Wahou" [Oahu], Gaudichaud, in 1827; Palolo, Rock nos. 10,063 and 12,512; and Bennett's from "Wouhala." It is obvious that the Hawaiian common name lauhala does not apply to *Santalum*. It means "leaves of the hala tree" (*Pandanus*) and was and is in very common usage in reference to mats, baskets, etc., plaited from the leaves of the *Pandanus;* thus Bennett's use of it for *Santalum* can be rejected as an error. Rock gave no explanation of the locality "Wouhala." The subsequent standard gazetteer of the Territory of Hawaii (Coulter, 1935) includes not only the place names on the current official topographic maps, but also the obsolete names or spellings from all available older maps. It does not include the place name Wouhala or anything like it.

The lengthy journal of Tyerman and Bennett has been scanned for data on this point. They arrived on Oahu in December, 1821, and spent more than 3 months on the island. Bennett gives an account of his ascent on April 26, 1822, of Erihi [Diamond Head], of climbing "the great mountain Punchbowl," and of climbing on April 28 the Koolau divide, not far from the Nuuanu Pali, "one of the highest accessible points in this island." He and his companion made a tour around the island of Oahu, but he does not in this account mention his finding of the sandalwood at "Wouhala." Bennett later mentioned the sandalwood and this locality, and gave a helpful description of the tree in his book (1860: 420–421), but this is a condensed and paraphrased account from the fuller one (1832: 260–261) which is here quoted:

> On the 10th of December, 1829 [1821], I visited the district of Wouhala (Island of Oahu); on ascending a high hill, the plains on the summit were found covered with dry grass, and various plants and shrubs, and at some parts deep wooded glens formed most picturesque and beautiful scenery. Among the specimens of plants, &c., I collected were the following:—
>
> A species of Cyathòdes, called pokeawi by the natives, bearing small red berries; the same native name is given to red beads, from their resemblance to the berries of this shrub. A species of Phytolacca, called poporo-tumai by the natives: the berries (which grow erect in long bunches) yield a reddish brown juice, used for dyeing the native cloth; the berries externally are of a purplish red colour; the leaves of the shrub are cooked and eaten.
>
> On the plains was found a species of Dianélla, named uki by the natives, bearing small berries of a mazarine blue, which are used by the natives in making a permanent blue dye. The *P*yrus *a*nthyllidifòlia of Smith (in Rees's *Cyclopaedia*), and more recently the Osteomèlis *a*nthyllidifòlia of Lindley (in the *Linnean Transactions*), called uré by the natives, was very abundant; it is a small shrub, bearing berries of a white colour, containing a reddish juice of sweet and astringent taste; the flowers are white and fragrant.
>
> The mamati or cloth plant, also named oreyna, the *U*rtica argéntea; the bark is used in the manufacture of the native cloth, and also produces a flax which might form a useful article of commerce. A species of Scaévola, named nouputa by the natives, was also abundant on the hills, bearing yellow flowers.
>
> A shrub, attaining the elevation of 9 or 10 ft., called karia or taria by the natives, was abundant, but the only specimens gathered had abortive flowers.
>
> A small tree, called lumma by the natives, had the leaves when young of a beautiful red colour, and the foliage has a peculiar appearance, apparently from minute glands situated on the upper and under surfaces. There is also a shrub (probably a Bass*ia*), called ohava, the seeds of which yield a red dye, used by the natives to stain their cheeks and fingers. A species of *G*naphalium, called poina by the natives, was also abundant.
>
> Of the uwara, or sweet potatoes (*C*onvólvulus *Batatas* et var.); which are much cultivated at the Sandwich Islands, there are seventeen varieties.
>
> On the declivities of the hills, and in the ravines, the tui tui, or candle nut tree (Aleurites triloba) is seen abundant; the whiteness of its foliage rendering it a conspicuous object. The whiteness is occasioned by a fine white powder on the upper surface of the leaf, which is readily removed by the finger. Under it the leaf is found of a dark green colour. The young foliage is thickly covered with this white powder; the older leaves have little, or are entirely destitute of it. The foliage of this tree varies much in form, depending on the age of the tree or leaves. The flowers grow in erect clusters, are small, white, and possessed of very little fragrance; the fruit is of small size,

globular, rough externally, and contains oily nuts, which, when baked and strung on a reed, are used by the natives of most of the Polynesian Islands as a substitute for candles or lamps, and burn with a clear and brilliant flame. The tree is branchy, attains an elevation of 30 ft. in height, and a circumference of 3 or 4 ft., the timber being of soft quality is useless, except as firewood. A gum is yielded by this tree, both spontaneously, and on incisions being made in the trunk. It is of a yellowish colour, inodorous and tasteless; the natives chew it, but the suspicious family [*Euphorbiaceae*] to which the tree belongs would render caution requisite in its use. I tried it, however, as mucilage for the suspension of some balsams, without any ill effects arising from it.

The turmeric plant (*Curcuma* lónga), called oreina by the natives, is abundant wild; the root, as well as that of the noni (Morinda citrifólia), is used for dyeing their native cloth of a bright yellow colour.

The foregoing account is quoted exactly as published, including the curious rendering of the scientific names, some unaccented, some with grave, some with acute accents, some in roman type, some in italics or partly so or even with only one letter in italics.[3] Probably Bennett's underlining of the scientific names to be set in italics in his manuscript was hasty, and the underlinings did not equal the names, though he intended them to do so. The printer did not interpret them thus; rather, he followed the copy exactly.

The plants mentioned in Bennett's account are now known as pukeawe (*Styphelia Tameiameiae*); popolo (*Phytolacca sandwicensis*); uki (*Dianella sandwicensis*); uulei (*Osteomeles anthyllidifolia*); mamake (*Pipturus albidus*); naupaka kuahiwi (*Scaevola Gaudichaudiana*); kalia (*Elaeocarpus bifidus*); lama (*Diospyros Hillebrandii*); kealia or alaea laau (*Bixa Orellana*); enaena (*Gnaphalium sandwicensium*); uala (*Ipomoea Batatas*); kukui (*Aleurites moluccana*); olena (*Curcuma longa*); and noni (*Morinda citrifolia*). Explanatory remarks are here appended for several of these plants.

[3] A few vowel accents unavailable to the printer of Pacific Science have been omitted. [Editor.]

The naupaka kuahiwi does not have yellow flowers. There is one native species which does, *Scaevola glabra,* but this grows only on the very crest of the mountains in the Cloud Zone. All indications are that Bennett did not on this day climb to the high peaks, but rather was describing collections made at the lower edge of the forest, in grassland or dry open forest. On Oahu, one of the commonest bushes and one of the first to be encountered on approaching the forest is *S. Gaudichaudiana,* which has white flowers with delicate magenta lines on the veins near the throat, but the flowers, when withering and drying on the bush, turn yellowish. It seems certain that this was the "nouputa" he noted. In confirmation of this, there was a specimen of *S. Gaudichaudiana* from Oahu, collected by Bennett, in the Berlin Herbarium (Skottsberg, 1927: 26).

Bennett's bush the "karia" is certainly kalia (*Elaeocarpus bifidus*), though truly a tree. The native name is a clear indication and the abortive flowers settle the question, for even today nearly every inflorescence through insect injury develops into a large, bright red, abnormal growth almost like a witches'-broom.

The "lumma" is evidently the lama (*Diospyros Hillebrandii*), which is conspicuous in the lower forest in spring because of its flush, or luxuriant young growth with abundant new crimson leaves, which is even more showy than the similar red flush on the cultivated mango tree. The leaves of the lama are not glandular, but both surfaces, and particularly the upper, are strongly salient rugose reticulate, with thin tissue between the meshes of the heavy close network. When looking through a leaf towards the light, Bennett may have mistaken the light intervals for glands.

Bennett's record of the name "ohava" is difficult to identify. There is no such name in the Hawaiian dictionaries or botanical works. The only similar name is hoawa

(*Pittosporum*), which native shrub or tree does not fill the bill. It seems fairly certain that instead, his tree is the introduced shrub kealia or alaea laau (*Bixa Orellana*). This is an American tropical shrub, of early introduction into the Hawaiian Islands, but just how early cannot now be definitely stated. Dr. W. T. Brigham (1911: 158), in his account of the dye plants used for coloring kapa (bark cloth), wrote:

> This shrub was formerly cultivated here for the red dye obtained by macerating the seed pulp, and has become naturalized in places. . . . I found it growing apparently wild in 1864 in Nuuanu and on the barren plains east of Kawaiahao church. . . . I believe that the old Hawaiians used the plant as a useful dye at least a century ago.

It is still commonly cultivated and occasionally naturalized in the islands. Brigham's estimate of its introduction would put the date at 1811. If this is correct, by 1831 there would have been plenty of time for it to have become dispersed among the Hawaiian villages. The Hawaiians have always been great plant lovers and skillful gardeners. Each attractive or useful plant has been spread among them with great rapidity.

The kealia is not a native plant, but neither is the uala (*Ipomoea Batatas*) nor the olena (*Curcuma longa*), which latter Bennett thought was growing wild. As Bennett was more zoologist than botanist, perhaps he should be excused for thinking the olena a wild plant. Many other explorers and botanists have been fooled by the gardens of the Polynesian peoples. Some of their crops, which need such culture, are planted and tended in well-cultivated fields. Others which grow well without care are planted at the base of the trees in a forest or on a grassy hillside where they grow as if wild, until the planter comes and harvests his crop. Many a botanist visiting a strange tropical island has recorded such plants as wild or native, when the situation is exactly the reverse, the plants being introduced economic species planted and owned by a tiller of the soil. The noni (*Morinda citrifolia*) is also a cultivated plant, but it seeds and tends to spread in the lowlands.

Bennett (1832: 257) gave more details concerning the sandalwood (*Santalum Freycinetianum*):

> At the Sandwich Islands, the tree is named iliahi or lauhala, signifying sweet wood (*lau,* wood, *hala,* sweet) [an error, the meaning being "leaf of the hala tree"; Bennett should have written laau, wood, aala, sweet]; and, when young, it is of very elegant growth. At Wouhala (Island of Oahu), I observed numbers of the young trees, some of which were covered by a profusion of beautiful flowers of a dark red colour; the flowers, however, are often observed to differ in colour on the same tree, and even on the same stalk; they grow in clusters, some having the corolla externally of a dark red colour, and internally of a dull yellow; others having it entirely of a dark red, and others again have the corolla partly red and white externally; the young leaves are of a dark red colour, and give an elegant appearance to the tree. This was not observed in the species found at the Island of Erromanga; indeed, the species found at the Sandwich Islands had a more handsome appearance in its growth than that at Erromanga. At the Sandwich Islands, two varieties of the wood are observed by the natives, depending, however, only on the age of the tree; the young or white wood is called lau, keo keo (*lau,* wood, *keo keo,* white); and the red wood, lau, hula hula (*lau,* wood, *hula hula,* red). [These are now written laau, wood; ulaula, red.] As before stated, the wood, when taken from a young tree, is white, containing but a small quantity of oil; as the tree increases in growth, the wood becomes of a yellowish colour, and the oldest and best is of a brownish red colour.* The different varieties of the wood depend, therefore, on the age of the tree; and are of three kinds, white, yellow, and red; of which the yellow and red, from containing the largest quantity of oil, are most esteemed in the Chinese market, where the wood is principally used, the expressed oil being mixed with pastiles, and burned before their idols in the temples. The Chinese are said to procure the oil by rasping the wood, and then expressing it through strong canvass bags.

* The wood is frequently buried, and the sap [sapwood] allowed to rot off: and this is considered to improve its quality. [AUTHOR'S NOTE.]

By assembling all the data from the plant associations and from the habitat, it has proved possible to spot Bennett's locality, "Wouhala," for the sandalwood. The asso-

ciated plants are characteristic of the lower edge of the dry forests. This habitat, up a high hill with dry, grass-covered plains on top, dissected by deep, wooded glens, is well described by him. Together these data apply to only one section of Oahu—the Leilehua plains or the broad pass between the Koolau and the Waianae Mountains. To avoid the deep, steep-walled gulches cut by the larger permanent streams from the Koolau Range, the old foot and horse trail over the pass kept close to the Waianae Mountains, swinging from Pearl Harbor toward the old hamlet of Lihue, keeping on the right (or east) the largest stream, Waikele, and its tributaries Kipapa and Waikakalaua Streams, all of which have cut deep gulches across the plateau or its slopes. On the upper reaches of Waikele Stream is Pouhala, about 1 mile south of Schofield Barracks and 1 mile north of Robinson Camp 1 (see Oahu topographic map, 1938 edition). The Wouhala of Bennett is surely Pouhala of today, because the description applies, the place is close to present localities for sandalwood, and Bennett is known to have journeyed through this area.

## PRESENT DISTRIBUTION ON OAHU

Accompanying this discussion is a map showing the present occurrence of *Santalum Freycinetianum* Gaud., a species restricted to the island of Oahu, and the only arborescent species on that island. This tree was doubtless the sole source of laau aala for the inhabitants of Oahu. On the map, the solid black dots mark localities for specimens with

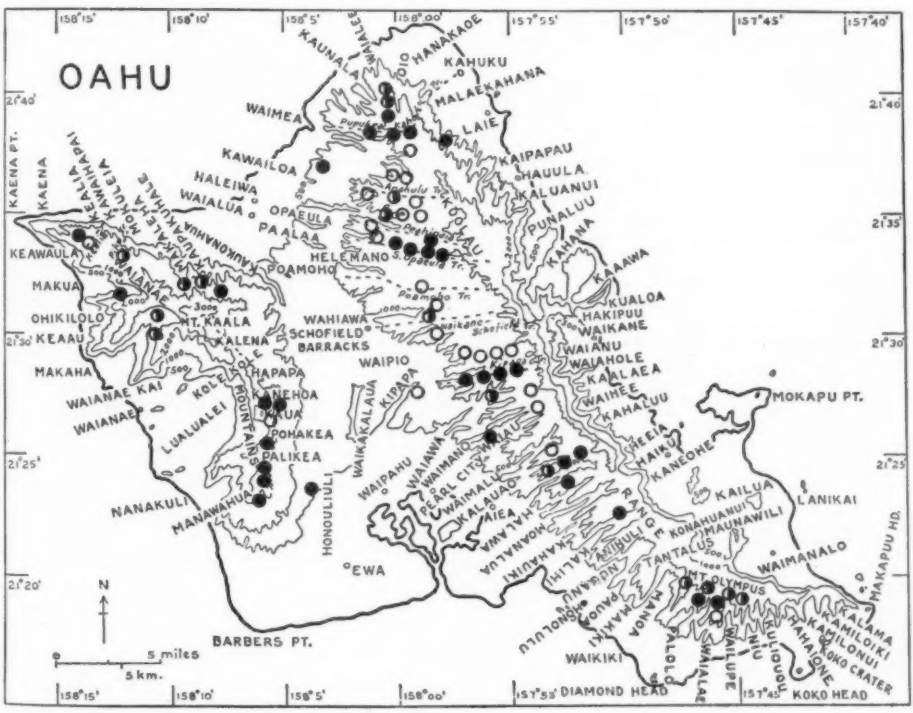



FIG. 1. Present distribution of sandalwood (*Santalum Freycinetianum*) on Oahu. Solid black dots mark the localities for specimens with exact data; half-black dots those with incomplete data; circles those recorded in field notes but without substantiating specimens.

exact locality data, such as part of valley, altitude, etc.; half-black dots mark the approximate place for specimens with indefinite data, such as name of valley or ahupuaa (land division) but nothing more; circles mark the localities without substantiating specimens but recorded in the field notes of William Meinecke, E. Y. Hosaka, or the writer. All these collections and records are subsequent to 1907 and so give a good index of the present distribution, which is wide, extending nearly from end to end of both mountain ranges. The tree is found on both sides of the Waianae Mountains from 500 to 2,400 feet altitude, but there is a break at Kolekole Pass, which is now treeless, denuded, and much eroded. Probably the tree occurred originally all across this stretch. Its absence now may be due to denudation by lumbering, forest fires, or cattle grazing. On the other hand, this low pass was a standard route of travel and was easily accessible to people coming either from the western villages in the Waianae region or from the broad Leilehua or Schofield saddle on the east. Its absence may also be due to despoliation by people in the sandalwood trade or by those in search of timber or fuel.

In the Koolau Range the sandalwood now occurs from 550 to 1,800 feet altitude, from the Niu-Wailupe Ridge to Kaunala and swinging around the northern end to Laie. The sloping north end of the Koolau Range is lower, and therefore does not receive as heavy a rainfall as the more elevated parts. It is noteworthy that on the windward or northeast side of the mountains and the windward shore, southeastward from Laie, there are no stations for the sandalwood. The whole shore and mountain slope is windier and rainier, so that the typical dry lower forest is not well developed here. Though koa (*Acacia Koa* Gray) is present, it does not form a definite zone, rather occurring scattered among other trees characteristic of wet forests. It will be recalled that in the old sandalwood tax collection record by Marin there were entries of 1,200 piculs from Cayrua, 800 from Caneoje, and 120 from Cajanu. If these names are correctly transliterated as Kailua, Kaneohe, and Kahana, they are districts where no tree sandalwood grows today, and where it is improbable that any ever did grow, the region being too wet. Yet these districts paid a tax in sandalwood. K. P. Emory has suggested to the writer that the men of these districts which lacked sandalwood may have been assigned to cut wood in crown lands in another district and thus to work off their taxes. The remaining districts all have sandalwood in the mountainous (mauka) inland sections. "Camejameja" was probably not the king, but Kamehameha, governor of part of Oahu. The collections entered under his name were made on several dates and are much larger than those from any single district.

Almost down to the present there has been a conspicous gap in the distribution of sandalwood on the lee (or southwestern) side of the Koolau Range, from Manoa to Moanalua. There is no old record, no published record, no herbarium specimen to represent this region, despite the fact that it is the most thoroughly botanized section in the Hawaiian Islands. All the early explorers came to Honolulu Harbor; later, the resident botanists mostly lived in Honolulu, and all of them repeatedly explored these ridges and valleys just behind Honolulu. As the habitat is suitable, this 8-mile gap is curious. Sandalwood is attractive, easily recognized; it thus has both historic and sentimental interest, and most botanists collect it every time they see it. Consequently the gap is probably not due to lack of collections. Andrew Bloxam (1925: 38) made a record of interest in his connection. On May 13, 1825, he and the botanist James Macrae made a trip up Nuuanu Valley toward the Nuuanu Pali, traversing the 4 or 5 miles

from the lower region, with its huts and taro patches, to the thick woods. He stated:

> We found a great variety of ferns and other plants among which the ginger plant was very prominent. We saw several of that beautiful tree the *Eugenia malaccensis,* or Malacca apple, in full bloom with its bright scarlet flowers, the dooe dooe, or oil nut [now called kukui, *Aleurites moluccana*] was very common. We could not find one sandalwood tree, all had probably been cut down about here for the purpose of barter.

This passage testifies to the early despoliation of the stands of sandalwood.

Still in search of records in the region behind Honolulu, the writer made inquiry of malacologists. The terrestrial and arboreal snails on the Hawaiian Islands are numerous, large, and of beautiful form and coloring. For more than a century they have been sought both by amateur nature lover and professional naturalist. As collections have accumulated it has become evident that many of the numerous species and subspecies have very restricted ranges, such as a single valley, or part of a valley, or even a single clump of trees. The land shell collectors become well acquainted with these localities and the species of trees favored by the snails. Thus, many of the collectors have an extensive and accurate knowledge of the native flora. Dr. C. M. Cooke, Jr., of the Bishop Museum, Honolulu, remembers seeing from 1890 to 1892 several sandalwood trees on the Kapalama-Waiolani ridge, just southwest of Napuumaia (in Nuuanu) at about 1,600 feet altitude. This was one of his best collecting localities, and he clearly remembers several sandalwood trees with their bright red, young leaves. George S. Waterhouse likewise remembers seeing sandalwood trees in the same locality between 1903 and 1906. He cut and carried down a good-sized log of the wood, which he kept for many years. He visited the locality frequently, for his brother, Fred Waterhouse, had a mountain cabin on the ridge at Napuumaia. This site is at 1,870 feet elevation on the west ridge of Nuuanu (see Kaneohe Quadrangle, Advance Sheet, surveyed in 1928). These two reports are considered fully trustworthy, and indicate that *S. Freycinetianum* persisted in Nuuanu as late as the beginning of the present century.

Finally, the writer was delighted on January 9, 1944, to find a single tree, 27 feet high and 10 inches in diameter, on the Kahauiki-Kalihi Ridge at 1,400 feet altitude. It was a vigorous, healthy tree, near the crest of the ridge in the Koa Zone. This collection, filed as H. St. John no. 20,444, fills in the gap and allows the conclusion that the sandalwood originally extended the length of the mountains and occurred on all the ridges behind Honolulu. Its scarcity or absence there now seems due to extermination. To supply the sandalwood trade, the large population of Honolulu would naturally seek the trees on the nearest accessible ridges, which were those behind the city. The resulting destruction of the trees by cutting as well as by heavy and destructive grazing by cattle nearly exterminated the sandalwood in these areas.

The former territorial superintendent of forestry, Charles S. Judd (1927: 43), in giving a detailed account of the sandalwood, stated:

> It is not likely, however, that sandalwood will soon, if ever, become much of a factor as a natural resource in the Territory because of the fact that it is of very slow growth, and before it can be artificially propagated with success, much more must be learned of its alleged parasitic habit of growth.

The sandalwood is widespread and occasional in the Waianae Mountains. In the Koolau Range (except behind Honolulu) it occurs on the lee side on nearly every secondary ridge, and is actually common at the lower edge of the forest in the Koa Zone and occasional up into the forest. Young trees are numerous, but so, too, are old trees.

No data have been published as to the rate of growth of this tree. At Kalauao

there are trees 20 feet tall, 6 inches in diameter; at South Opaeula Gulch trees 20 feet tall, 1 foot in diameter; at Laie-Malaekahana ridge a grove with trees up to 20 feet tall, 1 foot in diameter; and at Puu Peahinaia a tree 30 feet tall, 18 inches in diameter. Charles S. Judd (1939: 36) reported and printed a photograph of the largest tree he found, in Waola Valley, Kawailoa, 30 feet high, 21.3 inches in diameter. Territorial forest ranger Tom McGuire and the writer found a still larger one on September 28, 1943 (Fig. 2). It is near the north crest of a northern side ridge descending from the Anahulu Trail about one-fourth mile inside the Forest Reserve boundary at about 1,300 feet altitude. The tree had many branches and a wide spreading crown. As its trunk forked 4 feet from the ground, it was measured at 3 feet from the ground. It was 25 feet tall, 78½ inches in circumference, 28 inches in diameter.

FIG. 2. Largest known sandalwood tree (*Santalum Freycinetianum*) on Oahu, 28 inches in diameter, Kawailoa, September 28, 1943. The epiphytes are *Nephrolepis exaltata*. The figure is Harold St. John.

## RATE OF GROWTH

It is natural to inquire as to the rate of growth of *S. Freycinetianum*. A wood section was taken from a branch 1¼ inches in diameter, collected in 1932 by the writer at Paumalu on the Pupukea-Kahuku Trail at the north end of the Koolau Range. The wood was so hard that it was necessary to boil it for 3 days before it could be cut with a microtome knife. To the naked eye, faint, fairly regular rings were visible in a cut stub or in the transverse, stained microscopic section. Under the low-power lens of the compound microscope, these rings were also faintly visible. The wood was dense, of closely massed tracheids, small in diameter, thick walled, and uniform in all parts of the rings. The vessels were in radial rows, but irregularly spaced. The ray cells were uniform. The distinct banding which distinguished the rings was due to a grouping of cells with dark contents, probably tannin. The 15 or so rings might be annual rings, but this is not certain. Conditions are favorable for growth at all times of year on Oahu, as there are never freezing temperatures. There are, nevertheless, definite seasons to which all plants respond, flowering mostly in the spring and summer. There is a belief that these seasons are determined by a rainy and a dry season, but this does not seem to be substantiated. Weather records made

available by the Hawaiian Pineapple Company give data for three stations in the general region from which the wood sample was taken: at Opaeula, Paumalu, and Waimea No. 2. The last, in the upper pineapple fields by the lower edge of the forest above Waimea Camp at about 900 feet elevation, was the closest. Its yearly rainfall was very unequal in successive years. There were, of course, periods of greater rainfall, but at times two or three such wet periods occurred during a single year. These came often in December and August, but not constantly. Considerable differences between the rainfall even at adjacent stations indicate that the rain comes mostly from local showers. Sunshine and temperature records were not kept, but these would doubtless show a correlation with the rainfall. The rainfall records fail to show any regular annual maxima which could be correlated with growth rings. The rings noted in the sandalwood specimen are probably not annual rings, but rather wet season or sunny season rings, of which there are one or several each year. Hence, the rings do not clearly indicate the age of the stem. Long-term, precise observations are needed on trees grown beside a weather station before one can interpret rings such as those noted in the sandalwood.

FIG. 3. Sandalwood (*Santalum Freycinetianum*) tree 16 inches in diameter, Anahulu Trail, Kawailoa, 1,500 feet altitude, September 28, 1943, in lower, open forest, with dense fern undergrowth of *Cibotium Chamissoi* and *Dicranopteris linearis*. The figure is Tom McGuire.

Most of the trees of *S. Freycinetianum* known today are less than 18 inches in diameter (Fig. 3). It seems probable that all or nearly all of these have grown since the end of the Sandalwood Era in 1830. Larger trees such as the one on the Anahulu Trail, 28 inches in diameter, may well have been vigorous young trees that escaped destruction at that time.

## LOCATION OF ORIGINAL SANDALWOOD FORESTS

The present stands of *S. Freycinetianum* on Oahu are at the lower edge of the dry forest, and the tree is common, beginning at 1,000 or 1,200 feet altitude. Below this are outlying stations at much lower altitude: at Kawailoa, by the rim of the gulch north of the road running straight inland from Ashley, are healthy young trees at elevations as low as 600 feet (specimens collected September 28, 1943, St. John no. 20,364). This is 500 feet lower than, and 2 or 3 miles distant from, the lower edge of the forest.

Another record in the Koolau Range is of a single tree 20 feet tall, 18 inches in diameter, at 550 feet elevation on the north slope of Kipapa Gulch, 1¾ miles above the old territorial highway, and 2½ miles below the lowest forest stand in the gulch at about

750 feet altitude. This record was an observation made by E. Y. Hosaka while studying the flora and vegetation of Kipapa Gulch.

A third low station is in the Waianae Mountains, where a single 20-foot tree occurs in a dry lowland gulch below Puu Kuua at 500 feet elevation (specimens collected November 22, 1931, St. John no. 11,166). This is 2,000 feet below, and 3 miles distant from, the lower forest line near Palehua and Puu Manawahua, where the tree is again found. From the persistence of these isolated trees in the lowlands, even good-sized trees, there are indications that the sandalwood was originally much more common in the lowlands. There are also historic and other records which indicate the same early distribution.

Commander Charles Wilkes (1845, vol. 4: 78–79), reporting on a trip of the naturalists W. P. Rich and W. D. Brackenridge in 1840 from Waialua southward, says:

> The next day they proceeded on their way to Honolulu, across the plain between the two ranges of mountains. This plain, in the rainy season, affords abundance of food for cattle in three or four kinds of grasses, and is, as I have before remarked, susceptible of extensive cultivation by irrigation from the several streams that traverse it. The largest of the streams is the Ewa [Waikele]. Scraggy bushes of sandalwood and other shrubs are now scattered over a soil fit for the cultivation of sugar-cane and indigo.

Even in the time of Kamehameha I the sandalwood had been much depleted, so that this monarch put a kapu (ban) on the cutting of young trees. A contrary action, but arising from the same scarcity, was the burning of grassland or forest areas by the natives. This was done on the central plain of Oahu in order to detect standing or fallen logs of sandalwood by the sweet odor of their smoke. The flames, of course, killed many young sprouts and seedlings and prevented the recovery of the depleted stands of sandalwood or other trees.

B. Seemann (1853, vol. 2: 83), who visited Oahu in May, 1849, wrote:

> The Oahu Sandal-wood (*Santalum paniculatum*, Hook. et Arn.) [this Oahu species is now known to be *S. Freycinetianum* Gaud.], the Iliahi, or Laau ala (fragrant wood) of the Hawaiians, is now to be found in only one place, called Kuaohe, where it grows on the slopes of hills, close to the sea. Of the splendid groves, with the produce of which formerly so many ships were laden, but a few isolated bushes, which do not exceed three feet in height and an inch in diameter, remain, and these would probably disappear had they not been protected by the law, and thus escaped being converted into fuel.

There is also an exact German translation of this passage (Seemann, "Die Flora von Oahu," 1853: 31). The geographic name "Kuaohe" is unidentified, though Thomas G. Thrum (1904: 72) suggested doubtfully that it might be Kaneohe. This is very unlikely because the two names are dissimilar and the tree does not occur in that humid, wet region. As no recorded geographic name for any land division of whatever size is known that coincides with "Kuaohe," it remains unidentified. The name means "bamboo ridge."

The father of Edward Y. Hosaka is Yahei Hosaka, a farmer who settled in 1908 in Kipapa Gulch, Waipio, on the valley floor 3½ miles upstream from the bridge on the old paved territorial highway. On both sides of the gulch above his home the steep slopes had a forest cover with many sandalwood trees. The settlers cut the trees, destroying the forest to clear the land for the cultivation of pineapples. The koa (*Acacia Koa*) and ohia lehua (*Metrosideros collina* ssp. *polymorpha*) were used for firewood. As the sandalwood did not make good charcoal, they cut and burned it for mosquito punk.

According to a statement of Dr. H. L. Lyon in 1942, cord wood was formerly cut and hauled to Honolulu, where it was used for cooking and heating. In 1910–11 he examined piles of this cord wood in Wa-

hiawa, cut in the near-by gulches and ridges and destined for the kitchen stoves of Honolulu. A considerable proportion of the logs were sandalwood.

Numerous writers have recorded the decimation of the native forests on the Hawaiian Islands by many agents such as sandalwood cutters, grazing cattle, and fire, and by lumbering for firewood, timber, or charcoal. Hence, there is no doubt that the forests, until the coming of the white man, covered a large portion of the islands. On Oahu the forest did not stop at the 1,000- or 1,500-foot line, but came down in places right to the sea. What trees made up this forest cannot be completely known, but the trees now found at the lower, drier edge of the forest probably combined to form a forest over part of this area. They are the koa (*Acacia Koa*), olopua (*Osmanthus sandwicensis*), iliahi (*Santalum Freycinetianum*), aalii (*Dodonaea viscosa*), ohia ha (*Eugenia sandwicensis*), ohia lehua (*Metrosideros collina* ssp. *polymorpha* vars.), pukeawe (*Styphelia Tameiameiae*), kopiko (*Straussia Mariniana*), and naupaka kuahiwi (*Scaevola Gaudichaudiana*). The Leilehua or Schofield plains between the two mountain forests were densely and continuously forested. On the lowest, driest slopes, an open forest or savanna doubtless spread, largely of wiliwili (*Erythrina sandwicensis*) but also containing the ohe (*Reynoldsia sandwicensis*).

Charles S. Judd (1927: 43) expressed the opinion that the "sandalwood evidently never occurred in pure stands, but was found in small groups or as scattered individuals"; but Seemann (1853, vol. 2: 83) wrote of the splendid groves which formerly existed. To the writer, Judd's conclusion seems a better description of the present status than a reconstruction of the past. Professor J. F. Rock (1916: 13–14) had the same view as Seemann:

> Sandalwood must certainly have formed a large percentage of the tree growth in the drier regions or mixed forests, in the early days, before the value of the wood became known to the natives of these Islands. It must have existed in pure stands, or as forests, or it would have been next to impossible to export as much as $400,000 worth per annum.

*S. Freycinetianum* has recovered so far today as to be common and widespread, and at numerous parts of Kawailoa, Waimea, and Kaunala, it now forms the lower forest at 1,000 to 1,200 feet altitude. This is at the lower border of the present native forest, but not the natural lower limit of the sandalwood in former times. As E. Y. Hosaka observed during his 92 trips from 1931 to 1934 to study the vegetation of Kipapa Gulch, the sandalwood grew well there at the present lower edge of the forest at about 1,200 feet altitude. Lower down on the sides of the gulch at 700 and 800 feet altitude there were other sandalwood trees, definitely healthier and more vigorous than those above. This was true despite the fact that the surroundings were nearly denuded of native plants and trees, and were more exposed, drier, and more eroded.

The heaviest stands of former times were doubtless at lower elevations, below the Koa Forest Zone of that time. The existing outlying stations of old trees as low as 500 feet elevation, and the greater luxuriance at lower elevations, give an indication of where the old sandalwood stands were. As is true today, there were small stands on ridges or dry habitats far up into the forested mountains up to 2,000 or 2,400 feet altitude. Doubtless the large stands grew at even lower elevations than those of today, approaching or even reaching the shore in regions of moderate rainfall such as Kawailoa and Waimea, at the northern end of the Koolau Range. To judge by the many thousands of piculs of heartwood gathered, sandalwood must have been abundant. Hence, the writer deduces that there were heavy stands of sandalwood either abundant in, or dominant in, a forest zone from about 300

to about 1,000 feet altitude, below the Koa Zone and above the Wiliwili Zone. Probably the tree occurred on the lower, dry slopes of nearly every secondary ridge leading from the Waianae Mountains and on those leading from the leeward side and the north end of the Koolau Range. The northern and southern slopes of the Schofield saddle apparently had much more extensive stands of sandalwood, from Waimano to Honouliuli, and from Pupukea to Makaleha. This is a deduction from various types of evidence here assembled, which, for the first time, give an indication of the location of the principal stands of sandalwood on Oahu.

Though decimated by the sandalwood trade, the tree persisted on Oahu, survived the overgrazing and forest recession, and is now common and widespread at its former upper limit, now the lower forest line on the lee side of the Koolau Range and on both sides of the Waianae Mountains. Most of its present stations are protected from further destructive exploitation by their situation within the Territorial Forest Reserves.

## REFERENCES


BENNETT, GEORGE. An account of the sandal wood tree (Santalum), with observations on some of the botanical productions of the Sandwich Islands. *Mag. Nat. Hist.* (*Loudon's*) 5: 255–261, 1832.

——— *Gatherings of a naturalist in Australasia.* xii+456 p., 8 pl., 24 fig. John Van Vorst, London, 1860.

———, 1831. See MONTGOMERY.

BLOXAM, ANDREW. *Diary of Andrew Bloxam, naturalist of the "Blonde."* 96 p., 5 fig., 9 pl. Bernice P. Bishop Mus. Spec. Pub. 10. Honolulu, 1925.

BRADLEY, HAROLD W. *The American frontier in Hawaii: The pioneers, 1789–1843.* xi+488 p. Stanford Univ. Press, 1942.

BRIGHAM, WILLIAM T. *Ka hana kapa: The making of bark-cloth in Hawaii.* iv+273 p., 131 fig., 48 pl., 27 col. pl. Bernice P. Bishop Mus. Mem. 3. Honolulu, 1911.

COULTER, JOHN WESLEY. *A gazetteer of the Territory of Hawaii.* 241 p., 13 fig. Hawaii Univ. Res. Pub. 11. Honolulu, 1935.

DAVIS, C. Sandwich Islands. *North Amer. Rev.* 3: 52–53, 1816.

DELANO, AMASA. *A narrative of voyages and travels.* 598 p., 3 pl. E. G. House, Boston, 1817.

ELLIS, WILLIAM. *Narrative of a tour through Hawaii.* 442 p. H. Fisher & P. Jackson, London, 1826.

FISCHER, C. E. C. Where did the sandalwood tree (Santalum album Linn.) evolve? *Bombay Nat. Hist. Soc. Jour.* 40(3): 458–466, 1938.

HUNNEWELL, JAMES. *Voyage in the brig "Bordeaux Packet," Boston to Honolulu, 1817, and residence in Honolulu, 1817–1818.* 19 p. Hawaii. Hist. Soc. Papers 8. Honolulu, 1895.

INGRAHAM, JOSEPH. *Log of the brig "Hope," 1791.* 36 p., 2 pl. Hawaii. Hist. Soc. Reprints 3. Honolulu, 1918.

JUDD, CHARLES S. The natural resources of the Hawaiian forest regions and their conservation. *Hawaii. Forester and Agr.* 24(1): 40–47, 2 pl., 1927.

——— Report of Territorial Forester. *Hawaii Bd. Commrs. Agr. and Forestry Bien. Rpt.* 1938: 32–58, 4 pl., 1939.

KUYKENDALL, RALPH S., and HERBERT E. GREGORY. *A history of Hawaii.* x+375 p., illus. Macmillan, New York, 1926.

MATHISON, GILBERT FARQUHAR. *Narrative of a visit to Brazil, Chile, Peru, and the Sandwich Islands during the years 1821 and 1822.* xii+478 p. C. Knight, London, 1825.

MESICK, LILIAN SHREWSBURY. *The kingdom of Hawaii.* 400 p. Porter, Honolulu, 1934.

MONTGOMERY, JAMES (ed.). *Journal of voyages and travels by the Rev. Daniel Tyerman and George Bennet, Esq.* 2 vol. F. Westley & A. H. Davis, London, 1831.

"OLD QUARTER MASTER." *Thirty-six years of a seafaring life.* 336 p. W. Woodward, Portsea (England), 1839.

ROCK, JOSEPH F. The sandalwoods of Hawaii; a revision of the Hawaiian species of the genus Santalum. *Hawaii Bd. Commrs. Agr. and Forestry, Div. Forestry Bot. Bul.* 3: 1–43, 13 pl., 1916.

SEEMANN, BERTHOLD. *Narrative of voyage of H.M.S. "Herald" during the years 1845–51.* 2 vol. Reeve, London, 1853.

——— Die Flora von Oahu. *Bonplandia* 1: 30–32, 1853.

SKOTTSBERG, C. The geographical distribution of the sandalwoods and its significance. *Fourth Pacific Sci. Cong. Proc.* (Java), 3: 435–440, map, 17 fig., 1930.

THRUM, THOMAS G. The sandalwood trade of early Hawaii. *Thrum's Hawaiian Almanac and Annual for 1905,* 43–74. Honolulu, 1904.

WILKES, CHARLES. *Narrative of United States exploring expedition, 1838–1842.* 5 vol. Lea & Blanchard, Philadelphia, 1845.

# The Tsunami of April 1, 1946, in the Hawaiian Islands

G. A. MACDONALD, F. P. SHEPARD, and D. C. COX[1]

## INTRODUCTION

THE TSUNAMI WHICH STRUCK the shores of the Hawaiian Islands on the morning of April 1, 1946, was the most destructive, and one of the most violent, in the history of the islands. More than 150 persons were killed, principally by drowning, and at least 161 others were injured. Property damage reached about $25,000,000.

The wave attack on Hawaiian shores was far from uniform. The height and violence of the waves at adjacent points varied greatly, and not always in the manner which would have been expected from superficial inspection and a study of the existing literature on tsunamis. Therefore, a detailed study of the effects of the tsunami has been made, in an effort to understand the observed variations, and in the hope that the principles established may help lessen the loss of life and property in future tsunamis. Space is not available in the present short paper to discuss findings in detail, or even to present all the evidence for all the conclusions. These matters will be treated in detail in a longer paper (Shepard, Cox, and Macdonald, in preparation).

*Acknowledgments:* We wish to thank the many persons who furnished information during the course of the field study. We are also especially grateful to M. H. Carson, H. S. Leak, H. W. Beardin, and W. K. Sproat, who supplied measurements of the high-water level in areas not visited by us; H. W. Iversen and J. D. Isaacs, who supplied additional measurements on Oahu; A. F. Robinson and Dexter Fraser, who furnished descriptions of the wave effects on Niihau and Lanai, respectively; the Hawaii County Engineer's Office, which supplied a map showing the extent of flooding in Hilo; and the U. S. Coast and Geodetic Survey, which supplied data on the earthquake and the record of the Honolulu tide gage, and permitted the use, in advance of publication, of C. K. Green's manuscript on the tsunami along the shores of North and South America. Howard A. Powers, Seismologist of the Volcano Observatory at Hawaii National Park, aided greatly in the investigation on the island of Hawaii. Miss Maude Jones, Archivist of the Territory of Hawaii, and Miss Margaret Titcomb, Librarian of the Bishop Museum, aided in locating records of past waves. C. K. Wentworth and H. S. Palmer aided greatly in discussions. Wentworth and Walter Munk read and criticized the manuscript. J. Y. Nitta prepared the illustrations.

## DEFINITION OF "TSUNAMI"

The name "tsunami"[2] is applied to a long-period gravity wave in the ocean caused by a sudden large displacement of the sea bottom or shores. A tsunami is accompanied by a severe earthquake, but the earthquake does not cause the tsunami. Rather, both are caused by the same sudden crustal displacement. The waves of a tsunami have a period

[1] U. S. Geological Survey, Scripps Institution of Oceanography, and Hawaiian Sugar Planters' Association Experiment Station, respectively. This paper is published by permission of the Director, Geological Survey, U. S. Department of the Interior.

[2] Also spelled "tunami," the Japanese equivalent of the letter *t* being pronounced *ts* in English. It appears preferable, however, to use the phonetic spelling in English, avoiding thereby much incorrect pronunciation.

of several minutes to an hour as contrasted with several seconds for ordinary storm waves caused by wind, a wave length of scores of miles as contrasted with less than 500 feet for wind waves, and a speed of hundreds of miles an hour as contrasted with less than 60 miles an hour for wind waves. Tsunamis are also sometimes termed "seismic sea waves," and are popularly known as "tidal waves." The latter term is patently undesirable, as the waves have no connection whatever with the tides. "Tsunami" is used herein in preference to "seismic sea wave" because of its greater brevity, and because the etymological correctness of the term "seismic sea wave" appears open to question.[3]

## HISTORY OF TSUNAMIS IN HAWAII

Tsunamis probably reach Hawaiian shores on an average of more than one a year. Most of these are small, however, and generally escape notice except when their record is recognized on tide gages. Earlier tsunamis in Hawaii have been discussed by Jaggar (1931: 1–3) and Powers (1946: 3). The accompanying table lists all the tsunamis noticed on Hawaiian shores, in the period of written history, of which record could be found, together with their sources if known. A total of 27 are listed, or an average of one every 4.7 years since 1819. Most of them, however, did little damage. During the same interval there are listed five severe tsunamis which caused extensive damage, an average of one every 25.6 years.

Other violent waves have been termed "tidal waves" in the newspapers, but were more probably storm waves. Such were the wave which hit Maliko, Maui, on January 28, 1895, and those which struck Kaumalapau on Lanai, and Nawiliwili on Kauai, on May 30, 1924.

It will be noted that only two of the 27 tsunamis listed in the table were of local origin. With the exception of the numerous volcanic earthquakes on the island of Hawaii, which seldom cause tsunamis, the Hawaiian region is only moderately active seismically (Gutenberg and Richter, 1941: 84–85). The great majority of the tsunamis reaching Hawaii originate in the highly seismic border zone of the Pacific. Of the 22 tsunamis from known sources listed in the table, five came from near South America, one from near Central America, one from near California, three from near Alaska and the Aleutian Islands, five from near Kamchatka, three from the Japanese area, and one from near the Solomon Islands. Of the five severe tsunamis, three originated

TABLE 1

HAWAIIAN TSUNAMIS

| DATE | SOURCE | DAMAGE IN HAWAII | AVERAGE SPEED OF WAVES |
|---|---|---|---|
| | nearest coast | | mi. per hr. |
| 1819 Apr. 12 | Unknown | Unknown | — |
| 1837 Nov. 7 | South America | Severe | — |
| 1841 May 17 | Kamchatka | Small | — |
| 1868 Apr. 2 | Hawaii | Severe | — |
| 1868 Aug. 13 | South America | Severe | — |
| 1869 July 25 | South America (?) | Moderate | — |
| 1872 Aug. 23 | Hawaii | Small | — |
| 1877 May 10 | South America | Severe | — |
| 1883 Aug. 26 | East Indies | Small | — |
| 1896 June 15 | Japan | None | 478 |
| 1901 Aug. 9 | Japan (?) | None | — |
| 1906 Jan. 31 | Unknown | None | — |
| 1906 Aug. 16 | South America | Small | — |
| 1918 Sept. 7 | Kamchatka | Small | 456 |
| 1919 Apr. 30 | Unknown (distant) | None | — |
| 1922 Nov. 11 | South America | None | 450 |
| 1923 Feb. 3 | Kamchatka | Moderate | 432 |
| 1923 Apr. 13 | Kamchatka | None | 438 |
| 1927 Nov. 4 | California | None | 462 |
| 1927 Dec. 28 | Kamchatka | None | 438 |
| 1928 June 16 | Mexico | None | 462 |
| 1929 Mar. 6 | Aleutian Is. | None | 492 |
| 1931 Oct. 3 | Solomon Is. | None | 447 |
| 1933 Mar. 2 | Japan | Small | 477 |
| 1938 Nov. 10 | Alaska | None | 496 |
| 1944 Dec. 7 | Japan | None | 425 |
| 1946 Apr. 1 | Aleutian Is. | Severe | 490 |

[3] The adjective "seismic" is derived from the Greek root *seismos*, meaning earthquake, and is defined as pertaining to, produced by, or characteristic of an earthquake. The waves in question are not, however, characteristic of most earthquakes, even those of submarine origin, and are not produced by earthquakes.

near the coast of South America and one in the Aleutian area, and one was of local origin. One tsunami of moderate intensity came from near Kamchatka, and another probably from South America.

## GENERAL FEATURES OF THE APRIL, 1946, TSUNAMI: ORIGIN AND NATURE OF THE WAVES

The tsunami of April 1, 1946, was caused by a movement of the sea bottom on the northern slope of the Aleutian Deep, south of Unimak Island. The same crustal movement gave rise to a violent earthquake, recorded on seismographs all over the world. In Hawaii, it was recorded on the instrument of the U. S. Coast and Geodetic Survey located on the campus of the University of Hawaii in Honolulu, and on those of the Hawaiian Volcano Observatory at Kilauea on Hawaii. The epicenter of the earthquake has been located by the Coast and Geodetic Survey at latitude 53.5° N. and longitude 163° W., and the time established as $1^h$ $59^m$ A.M. Hawaiian time ($12^h29^m$ Greenwich time) (Bodle, 1946: 464). It may be assumed that the tsunami originated at the same place and time as the earthquake. The place of origin was thus 2,241 miles N. 8.5° W. of Honolulu, and 2,375 miles N. 12° W. of Hilo (Fig. 1).

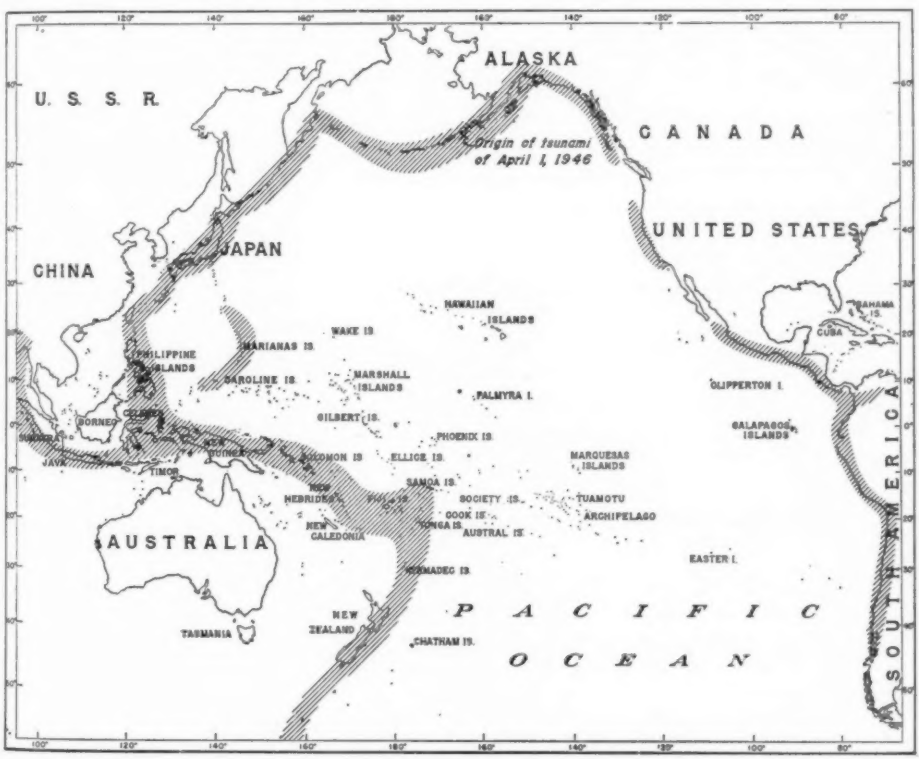



FIG. 1. Map of the Pacific basin, showing the position of the Hawaiian Islands, the place of origin of the tsunami of April 1, 1946, and the distribution of seismically active belts around the Pacific in which tsunamis are likely to originate.

The time of arrival of the waves in the Hawaiian Islands is known with certainty only at Honolulu. The record of the Honolulu tide gage (Fig. 2) shows that the first rise started at about 6:33 A.M. (Green, C. K., 1946: 491), though the exact time cannot be stated closer than 2 or 3 minutes. The drum of the water-stage recorder at the Waimea River, on Kauai, revolves too slowly to give an accurate indication of time, but the first rise appears to have started there at about 5:55. At Hilo, electric clocks were stopped at 7:06, and a brief power failure occurred at 7:18. These have been interpreted by Powers (1946: 2), probably correctly, as the time of arrival of two wave crests at Hilo. From other considerations, discussed briefly elsewhere (Shepard, Macdonald, and Cox, in preparation), it appears probable, however, that the crest at 7:06 was the second wave at Hilo, not the first. If so, allowing for the observed 15-minute interval between later waves, the first rise at Hilo probably started at about 6:45. Computed from these times of arrival, the approximate average speed of the tsunami from its origin to Honolulu and Hilo was, respectively, 490 and 498 miles an hour. On entering shallow water the waves decreased greatly in speed. The waves moving up Kawela Bay, on Oahu, were estimated by Shepard to be moving only about 15 miles an hour. Similar low speeds near shore were reported by other observers, and are comparable to the speed of 20 miles an hour recorded in San Francisco Bay (Green, C. K., 1946: 492).

The interval between the first and third wave crests, as recorded on the Honolulu tide gage (Fig. 2), was about 25 minutes, indi-

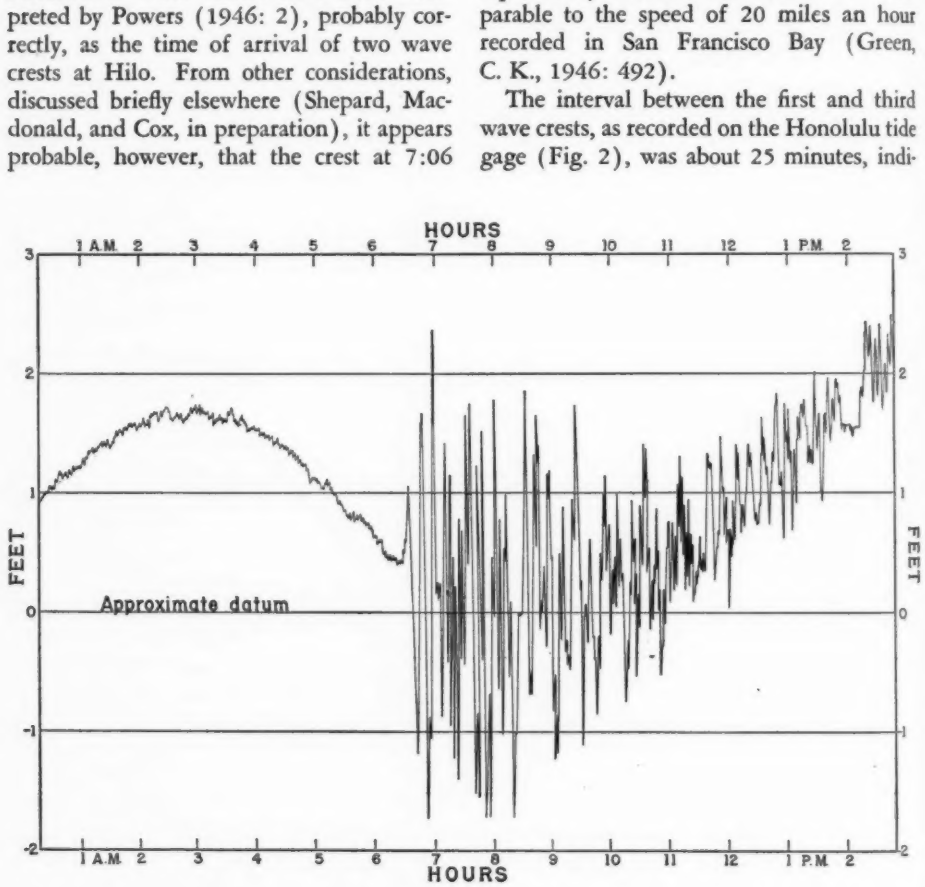



FIG. 2. Record produced on the tide gage in Honolulu Harbor by the tsunami of April 1, 1946.

cating an average interval between early wave crests of approximately 12.5 minutes. The interval between the first wave crest and the succeeding trough was 7.5 minutes, however, indicating a wave period of 15 minutes at the beginning of the disturbance. This corresponds with the mean wave period of 15.6 minutes found by Green (1946: 499) at Honolulu and eight other stations on the coasts of North and South America. At the mouth of Nuuanu Stream in Honolulu, C. K. Wentworth observed an interval of approximately 15 minutes between successive bores ascending the stream, and a wave period of about 15 minutes was observed by J. B. Cox and D. C. Cox at Waikiki at about 7:45 A.M. Observations elsewhere were poor, but in general indicated an interval not far from 15 minutes between the early waves of the series. The interval between later waves at Honolulu (Fig. 2) and elsewhere was shorter and less regular, probably because of the arrival of chains of waves traveling by somewhat different routes, refracted around different sides of islands, and reflected at various points, as well as traveling by the most direct route. Probably contributing to the irregularity of later waves were wind waves and also the free-period oscillations, in harbors and channels, known as "seiches." If the period of the waves is assumed to be 15 minutes, and the average speed to be about 489 miles an hour, the average wave length from crest to crest was about 122 miles.

Direct observations on the height of the waves in the open sea are lacking, but theoretical considerations indicate that the height probably did not exceed 2 feet from crest to trough.[4] If so, the small height combined with the very great wave length should have made the waves imperceptible to ships at sea. That such was indeed the case is indicated by the fact that the master of a ship lying offshore near Hilo could feel no unusual waves, although he could see the great waves breaking onshore. Crews of fishing boats in the Hawaiian area also reported no unusual conditions at the time of the tsunami, although heavy storm waves were running. The few reports of violent waves of great height from ships at sea were probably occasioned by storm waves, together with the knowledge that a tsunami was taking place.

The nature of the waves sweeping up on to Hawaiian shores varied greatly from place to place. At some places the water rose gently, flooding over the coastal lands without the development of any steep wave front. At such places most of the damage resulted from the violent run-back of the water to the sea. At some localities, although the general water surface rose gently, ordinary storm waves moved in over the top of the broad swells of the tsunami, and there at least part of the damage was caused by the storm waves. At most places, however, the waves of the tsunami swept toward shore with steep fronts and great turbulence, causing a loud roaring and hissing noise. Locally, the wave closely resembled a tidal bore, the steep front rolling in over comparatively quiet water in front of it. Behind the steep front, the wave crest was broad and nearly flat, with smaller storm waves superimposed upon it. Such bores were best developed in bays and estuaries, but waves of closely similar form were observed crossing shallowly submerged reefs upon otherwise open coasts.

At many places the violence of the waves moving shoreward was sufficiently great to tear loose heads of coral and algae, up to 4 feet across, and toss them onto the beach as much as 15 feet above sea level. Locally, blocks of reef rock weighing several tons were quarried at the outer edge of the reef and thrown onto the reef surface.

Between crests, the water withdrew from shore, exposing reefs, coastal mud flats, and

[4] Based on the assumption of a 10-foot wave in 10 feet of water, and the variation of the wave height inversely as the fourth root of the depth.

harbor bottoms for distances up to 500 feet or more from the normal strand line. The outflow of the water was rapid and turbulent, making a loud hissing, roaring, and rattling noise. At several places houses were carried out to sea, and in some areas even large rocks and blocks of concrete were carried out onto the reefs. Sand beaches were strongly eroded by the outgoing water. People and their belongings were swept to sea, some being rescued hours later by boats and life rafts dropped from planes.

At a few places, generally but not exclusively on the sides of the islands away from the wave origin, the first wave was reported to have been the highest. At those places, the rise was generally of the quiet sort. There are, however, no instrumental records showing the first wave to have been the highest, and it is possible that at places reporting the first wave as the highest, earlier waves may have been overlooked. Much more generally the third or fourth wave was reported to have been the highest and most violent. The third crest was the largest at the Honolulu tide gage (Fig. 2). At other localities the sixth, seventh, or eighth waves were said to have been the highest. At Waimea River, Kauai, the sixth crest was higher than any other, both in absolute level and in its height above the preceding and succeeding troughs.

In general, if not everywhere, the size and violence of the waves increased to a maximum with the third to eighth waves. The oscillations then gradually decreased in amplitude over a period of at least 2 days, but with occasional waves which were larger than those just before and after them. Such temporary increases in wave height probably resulted from mutual reinforcement by the essentially simultaneous arrival, in phase, of waves which had traveled different paths, or from the coincidence of tsunami waves with storm waves or seiche oscillations.

Measures of the height of the waves approaching shore in shallow water, but before they dashed up on shore, are poor. At Kawela Bay, Oahu, Shepard estimated the height of the waves advancing across the reef to have been as much as 18 feet, and observers estimated the height of the waves crossing the reef off Lanikai, on Oahu, to have been about 7 feet. Photographs taken at Hilo show the top of the breakers to have been 25 feet above the normal bay surface where they struck Cocoanut Island, but the waves may have increased considerably in height in crossing the breakwater, and the effect of dashing up on the shore was probably already present, further exaggerating the height. Photographs of some of the late waves at the mouth of the Wailuku River, in Hilo, show them to have been 6 to 8 feet high (Plate 8), and early waves undoubtedly were higher. In general, these heights correspond fairly closely with the measured heights to which the water dashed on the shore at those localities. At any rate it appears clear that the waves not only slowed down, but increased in height on entering shallow water. George Green (1838: 457–462) states that the wave height varies inversely as the fourth root of the depth of the water.

Most observers reported the first movement on Hawaiian shores to have been a withdrawal of the water. However, the only available instrumental records, at Honolulu and Waimea, both indicate the first movement to have been a rise. The instrumental records are probably more reliable than the reports of untrained observers. The initial rise at Honolulu was small (Fig. 2), and a similar small rise at other localities may easily have been overlooked. Certainly it would have been less impressive than the large withdrawal of the water from shore as the succeeding trough approached. It is interesting to note that the records of tide gages along the coasts of North and South America obtained by C. K. Green (1946: 497) all show the initial movement to have been a

rise, with amplitude of about one third that of the ensuing trough.

### HEIGHTS REACHED BY THE WAVES ON HAWAIIAN SHORES

Measurements of high-water marks have been made around the shores of all five major islands of the Hawaiian group. The measured heights are shown on Fig. 3 to 7. All heights are stated in feet above lower low water. At each point sea level was estimated, the height of the high-water mark above that level was measured by means of hand level or steel tape, and the measurement reduced by means of tide tables to height above lower low water. Some inaccuracy undoubtedly has entered in the estimation of mean sea level, but it is believed that the heights are probably accurate to within 1 foot. The levels measured include: points indicated by eyewitnesses as the upper limit of the water, lines of flotsam or swash marks, the upper limits of soil and vegetation scouring, levels of consistent scratching and barking on trees, and the upper level of staining on the walls of buildings.

The measured heights of high-water marks range from 55 feet at Pololu Valley

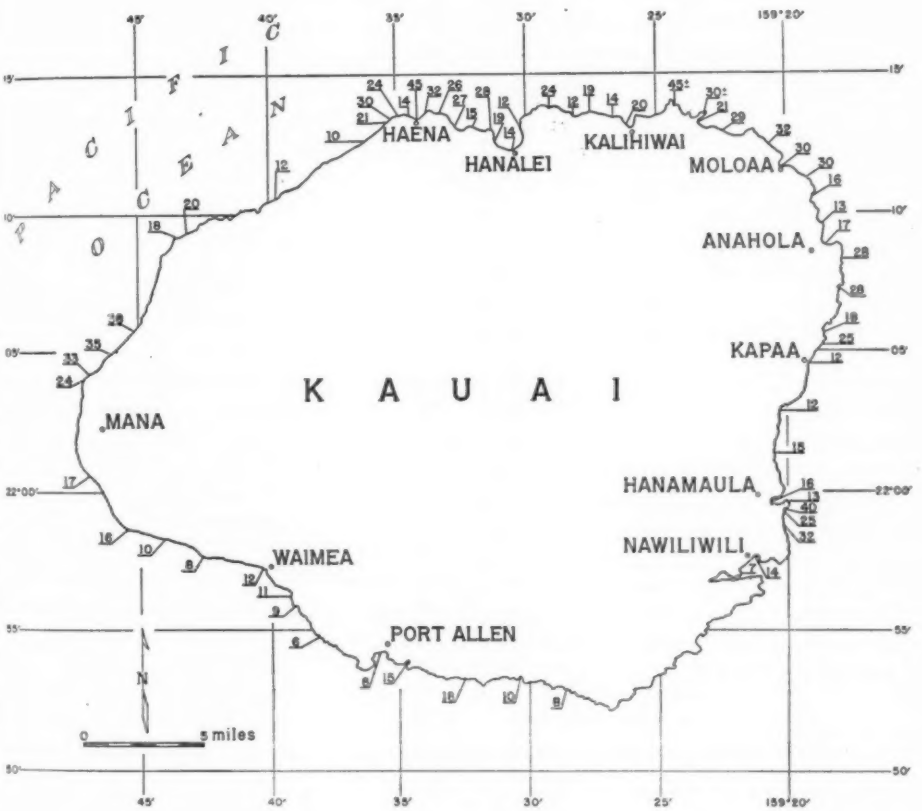



FIG. 3. Map of the island of Kauai, showing heights reached by the water during the tsunami of April 1, 1946. Heights are in feet above lower low water.

on Hawaii, 54 feet at Waikolu Valley on Molokai, and 45 feet at Haena and Kilauea Point on Kauai, to 2 feet at Kaunakakai on Molokai, 2 feet at Milolii and Hoopuloa on Hawaii, and less than 2 feet at the head of Kaneohe Bay on Oahu. Causes of the variations in height will be discussed in a later section.

Most of the heights measured are, of course, not the heights of the actual waves, but rather the heights to which the water was driven on shore. On a vertical cliff directly across the path of the wave, this height may theoretically amount to twice the height of the actual wave. On slopes less than vertical, or on cliffs at an angle to the direction of wave advance, it should be somewhat less than twice the wave height. This measure represents the height of dash of solid water, but very abundant spray may be thrown much higher. Moreover, storm waves riding on the crest of the broader swells of the tsunami undoubtedly added in places to the height to which water dashed on shore. There are places where normal trade-wind waves are flung to a height nearly as great as that reached by the tsunami, and many places, particularly on shores facing away from the origin of the tsunami, where waves of heavy storms reached appreciably higher than did the waves of the tsunami.

It is not possible to make reliable estimates of the magnitudes of these complicating factors, as there are too many unknown elements involved. However, it is probable that most of the water heights recorded for the tsunami on the northern and eastern sides of the islands were appreciably increased by these factors.

## FACTORS INFLUENCING THE HEIGHTS AND INTENSITIES OF THE WAVES

It may be assumed that the size and speed of the waves approaching the islands from the open ocean to the north were essentially the same throughout the length of the Hawaiian Archipelago. Differences in height reached by the water and in violence of wave attack along Hawaiian shores must be attributed to local influences modifying the size and behavior of the waves.

The factors found to have affected the height and intensity of the waves during the tsunami of April 1, 1946, are:

1. Orientation of the coast line with respect to the point of origin of the tsunami.
2. Shape of the island.
3. Exposure to storm waves.
4. Submarine topography.
5. Presence or absence of reefs.
6. Configuration of the coast line.
7. Merging of waves from different directions, or of different types.

*Orientation of the coast line with respect to the point of origin of the tsunami.*—In general, the heights reached by the water were greatest on the sides of the islands facing the origin of the waves, and lowest on the sides away from the wave origin. This is evident from even a cursory inspection of the maps (Fig. 3 to 7). Heights average consistently greater on the northern than on the southern sides of the islands. All the extreme heights were measured on the northern or northeastern sides. Conversely, most of the lowest figures were found on the southern and southwestern sides. It appears almost self-evident that this should be so. Waves striking northern shores retain their full force, whereas the refracted waves striking southern shores suffer a diminution in force and height. This effect is discussed for wind waves in *Breakers and surf* (U. S. Navy Hydrographic Office, 1944: 12–13). No wave can be refracted or reflected without losing some of its force.

*Shape of the island.*—Waves were refracted around circular or nearly circular islands much more effectively than around angular or elongate islands. This fact had a marked effect on the height and violence of waves on

the southern shores. Thus the water reached considerably greater heights along the southern coast of the nearly round island of Kauai (Fig. 3) than along the southern coast of the angular and elongate island of Molokai (Fig. 5), even though the heights along the northern coast of Molokai were on the average perhaps a little greater than those on the northern coast of Kauai. The contrast between the very high average height on the northern coast of Molokai and the very low average height on the southern coast is greater than that between the two sides of any other island, although the difference between the extreme highs and lows is almost exactly the same as on the island of Hawaii (Fig. 7).

*Exposure to storm waves.*—At the time of the tsunami, large storm waves had been running for several days. As already pointed out, these storm waves riding in on the backs of the broad swells of the tsunami in places undoubtedly increased the height to which the water dashed on shore. Moreover, in other places, where the rise in water level due to the tsunami was gentle, storm waves on top of the tsunami were responsible for much of the damage. The generally greater violence of the waves on the windward (northern and northeastern) coasts as compared to that on the leeward coasts may have been in considerable part the result of the large storm waves which were driving in on the windward coasts. Places on the wind-

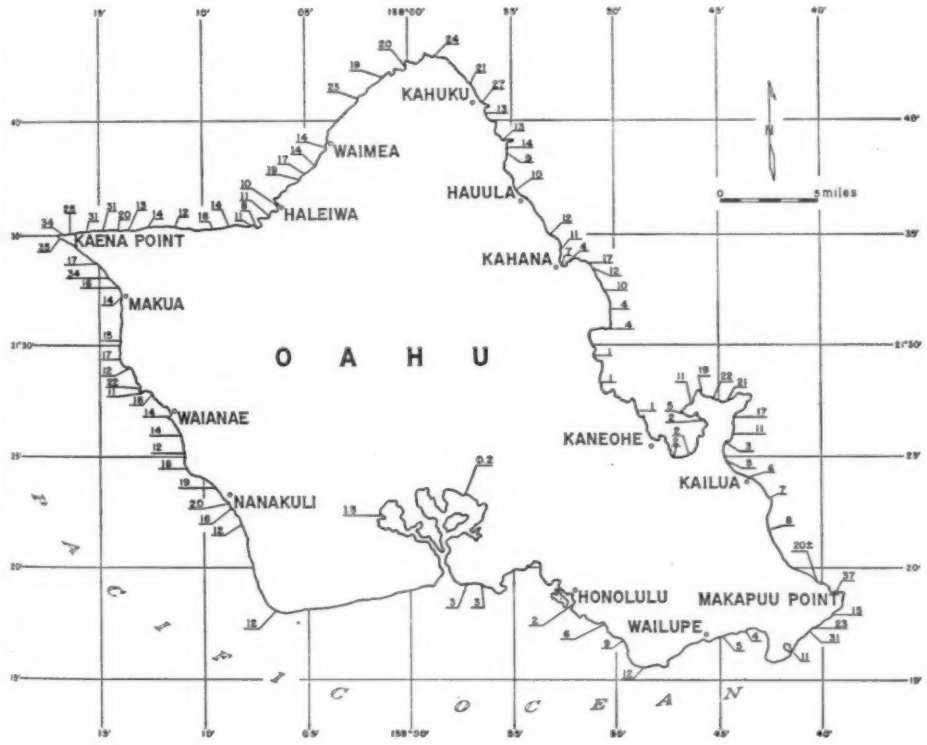



FIG. 4. Map of the island of Oahu, showing the heights reached by the water during the tsunami of April 1, 1946. Heights are in feet above lower low water.

ward coasts which were sheltered from the storm waves also experienced less violent waves. Thus at Kalaupapa, on the sheltered side of the peninsula on the windward side of Molokai, both photographs and the testimony of observers indicate that the rise of 25 feet caused by the tsunami was not violent. On the windward coasts, much of the rapid variation in intensity of wave attack may have resulted from the caprice of storm waves.

*Submarine topography.* — Owing to their great wave length, the waves were somewhat affected by the ocean bottom throughout their course. However, the effect of the bottom increased greatly as the waves moved into shallow water, and caused a slowing of the wave, an increase in its height, and a steepening of its front. A direct evidence of the increase in height of the waves in shallow water was afforded by the lesser heights reached by the water at the ends of certain peninsulas projecting into deep water and not prolonged seaward by pronounced ridges, as compared with the heights on adjacent shores rising from shoal water. Thus at the end of Kalaupapa Peninsula, on the northern coast of Molokai (Fig. 5), the water dashed only 7 feet above normal sea level, distinctly less than do the waves of ordinary storms; whereas on the coasts rising from shoal water both east and west of the peninsula, the water swept up to heights of 30 to 54 feet. At the end of Keanae Peninsula, on the northern coast of Maui (Fig. 6), the tsunami reached heights only a little greater than large trade-wind waves.

Submarine ridges and valleys, particularly those pointing toward the wave source, were of great importance in their effect on the strength of the waves. The best examples of the effect of ridges are found on the northern coast of Kauai. A long ridge extends in a direction slightly west of north from Haena, to a depth of about 8,000 feet (Plate 2). Another extends northeastward from Kilauea Point, to even greater depths. The greatest heights (45 feet) reached by the water on the shores of Kauai were at the heads of these two ridges (Fig. 3). Another ridge extending northwestward from the western coast of Kauai is probably responsible for heights of 35 to 38 feet at its head. Long ridges projecting from Kaena and Kahuku Points on Oahu similarly caused an increase in wave heights there as compared to the heights on both sides (Fig. 4). The ridges projecting eastward north of Hilo Bay and at Cape Kumukahi on Hawaii had, on the other hand, no such pronounced

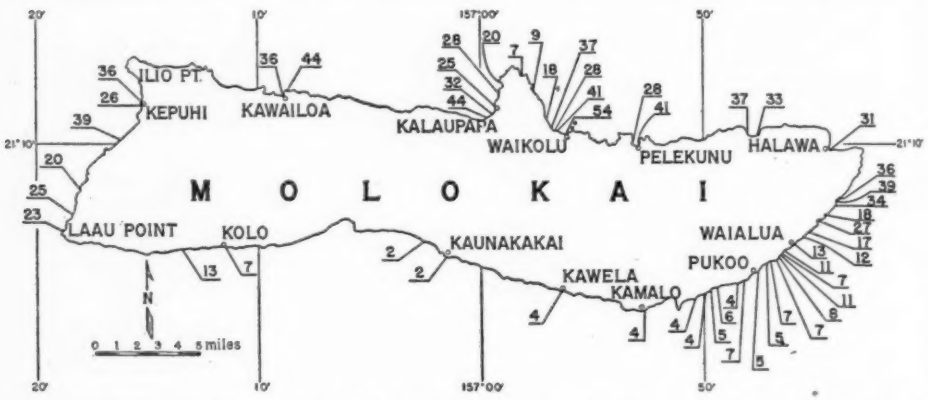



FIG. 5. Map of the island of Molokai, showing heights (in feet above lower low water) reached by the water during the tsunami of April 1, 1946.

effect on the heights at their heads; but it should be noted that they extend across the general direction of wave advance, not toward it.

The greater heights reached by the water at the heads of submarine ridges are not difficult to explain. The ridge has a greater effect in limiting the movement of water particles in the advancing wave than does the deeper water alongside it. Consequently the portion of the wave over the ridge is retarded more than that away from the ridge, and the wave front becomes bent, with its concavity directed toward the ridge head. The result is a focusing of wave force on the shore at the head of the ridge (U. S. Navy Hydrographic Office, 1944: 13).

Similarly, in moving toward shore along the axis of a submarine valley, the part of the wave in the deep water along the valley axis moves faster than that in shallower water on the two sides. In consequence the wave front becomes bent, with its convexity toward the valley head. In the vicinity of the valley head the force lines (orthogonals) of the wave are diffused or spread apart, and over any unit area the force of the waves striking shore is greatly decreased.

An example of the effect of a submarine valley in lessening the force of the waves at its head is found at Kahana Bay, on Oahu (Fig. 4). There the waves dashed to heights of 11 to 17 feet on the coasts north and south of the bay, but reached heights of only 4 to 7 feet in the bay itself. A small submarine valley extends 2 miles northeastward from the bay, to a depth of 150 feet. An example on a much larger scale is af-

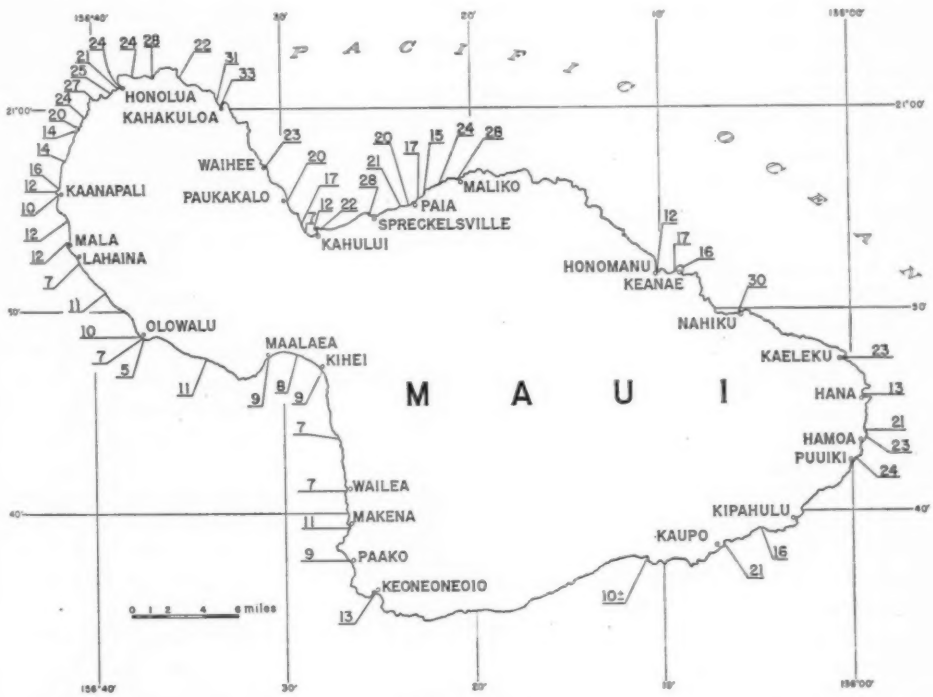



FIG. 6. Map of the island of Maui, showing heights (in feet above lower low water) reached by the water during the tsunami of April 1, 1946.

forded by the zone of small heights along the northwestern shore of Kauai (Fig. 3), at the head of a broad swale extending outward to oceanic depths. The broad valley-like depression off the eastern coast of Hawaii south of Hilo Bay probably also was somewhat effective in reducing the heights reached by the water along that coast. Although fairly great, ranging from 16 to 19 feet, the heights there are not much greater than those reached by ordinary storm waves.

*Presence or absence of reefs.*—The presence of a well-developed fringing reef appears to have had a decided effect in reducing the intensity of wave onslaught. Along the reef-protected northern coast of Oahu the heights reached on shore by the waves were on the average decidedly less than on the unprotected northern coasts of Molokai and Hawaii, or on the less protected northern coast of Kauai. The best-developed coral reef in the Hawaiian Islands fills Kaneohe Bay on Oahu, where it has a width of about 3 miles. Despite the fact that the broad mouth of Kaneohe Bay is open to the north and northeast, the tsunami produced a rise in water level at the bay head which was so small as to be hardly perceptible to observers, and, so far as could be determined, nowhere exceeded 2 feet. Along the shore north of the bay the heights ranged from 4 to 10 feet, and on the end of Mokapu Peninsula southeast of the bay the heights reached more than 20 feet (Fig. 4).

The lesser heights along the southern shore of Molokai were probably partly due to the wide protecting reef. The effect of the reef in reducing wave violence along that shore is well shown at places where channels cross the reef. There the waves striking the shore at the heads of the channels were distinctly larger than those reaching shore on each side of the channel. Thus at the head of a small channel which crosses the reef just west of the mouth of Kainalu Stream the water rose 11 feet, damaging houses, whereas just east and west of this channel the water rose only 7 to 8 feet.

*Configuration of the coast line.*—It is generally considered that the effects of tsunamis should be intensified near the heads of V-shaped embayments. Such embayments greatly increase tidal fluctuations, as in the Bay of Fundy, and might be expected to act likewise on the similarly long waves of a tsunami. Imamura (1937: 125–127) states that as such a wave rolls up a V-shaped embayment its height increases in inverse ratio to the width and depth of the bay, and cites examples of such increases in height of the waves toward the bay head during Japanese tsunamis. Consequently, special search was made for this phenomenon in funnel-shaped bays on Hawaiian shores. No good examples could be found. Hilo Bay would appear to be an almost ideal site for such funneling, but measurements around its shores show no systematic increase in heights toward its head (Fig. 7 and Plate 1). Similarly there was a lack of increase in heights toward the head of the broad V-shaped embayment on the northern coast of Maui. Possibly the extreme height of 54 feet at Waikolu Valley, on the northern shore of Molokai, may have been partly the result of funneling between Kalaupapa Peninsula and the point and small islands just east of the mouth of the valley. At both Pololu Valley on Hawaii and Pelekunu Valley on Molokai, the water level was higher at the bay head than on the walls of the bay part way out. However, at Pololu Valley, and probably also at Pelekunu, this level was the result of a local upsurge where the waves crossed the beach. Conversely, several bays were found in which the heights reached by the water were less at the bay head than near its mouth.

Several small steep valleys, debouching into small bays, were found in which the water rose to appreciably greater heights along the valley axis than on the sides near the bay mouth or opposite the beach. Thus,

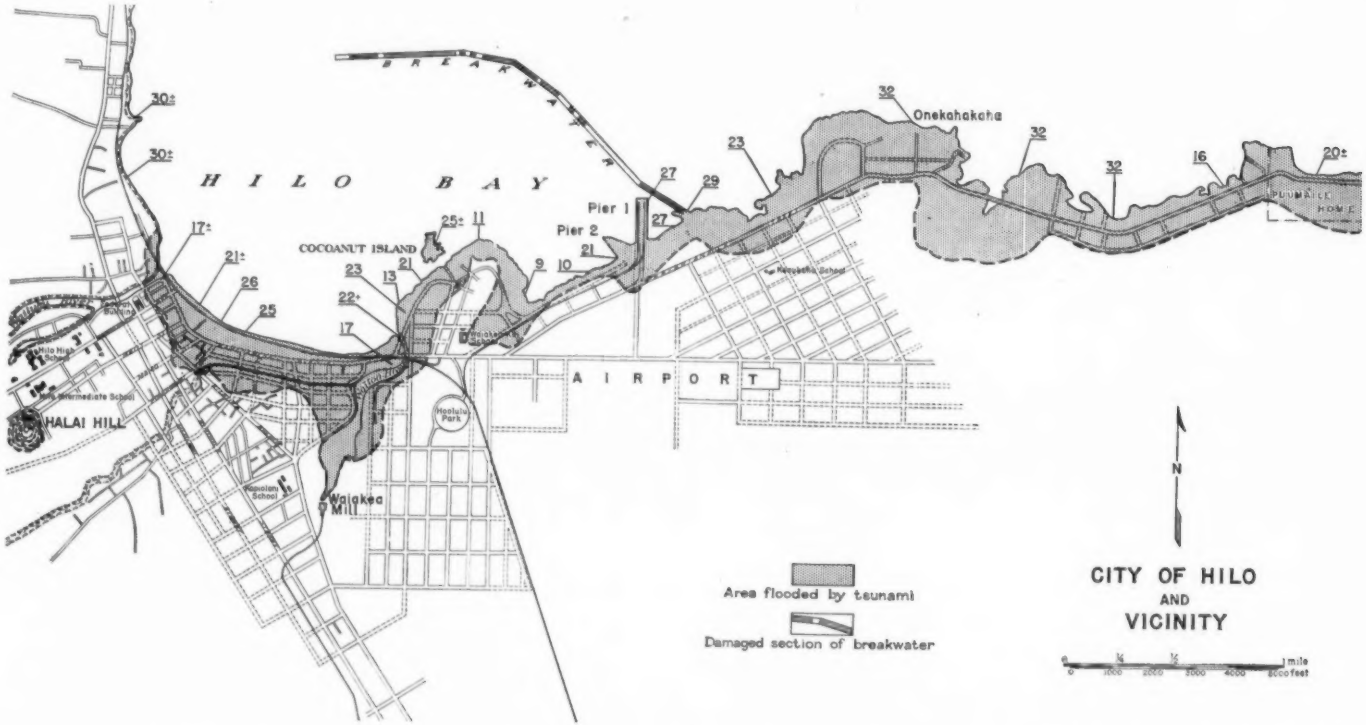



PLATE 1. Map of the Hilo area on the island of Hawaii, showing the heights reached by the water, the area of flooding, and the portion of the breakwater destroyed (shaded portions) during the tsunami of April 1, 1946. Heights are in feet above lower low water.

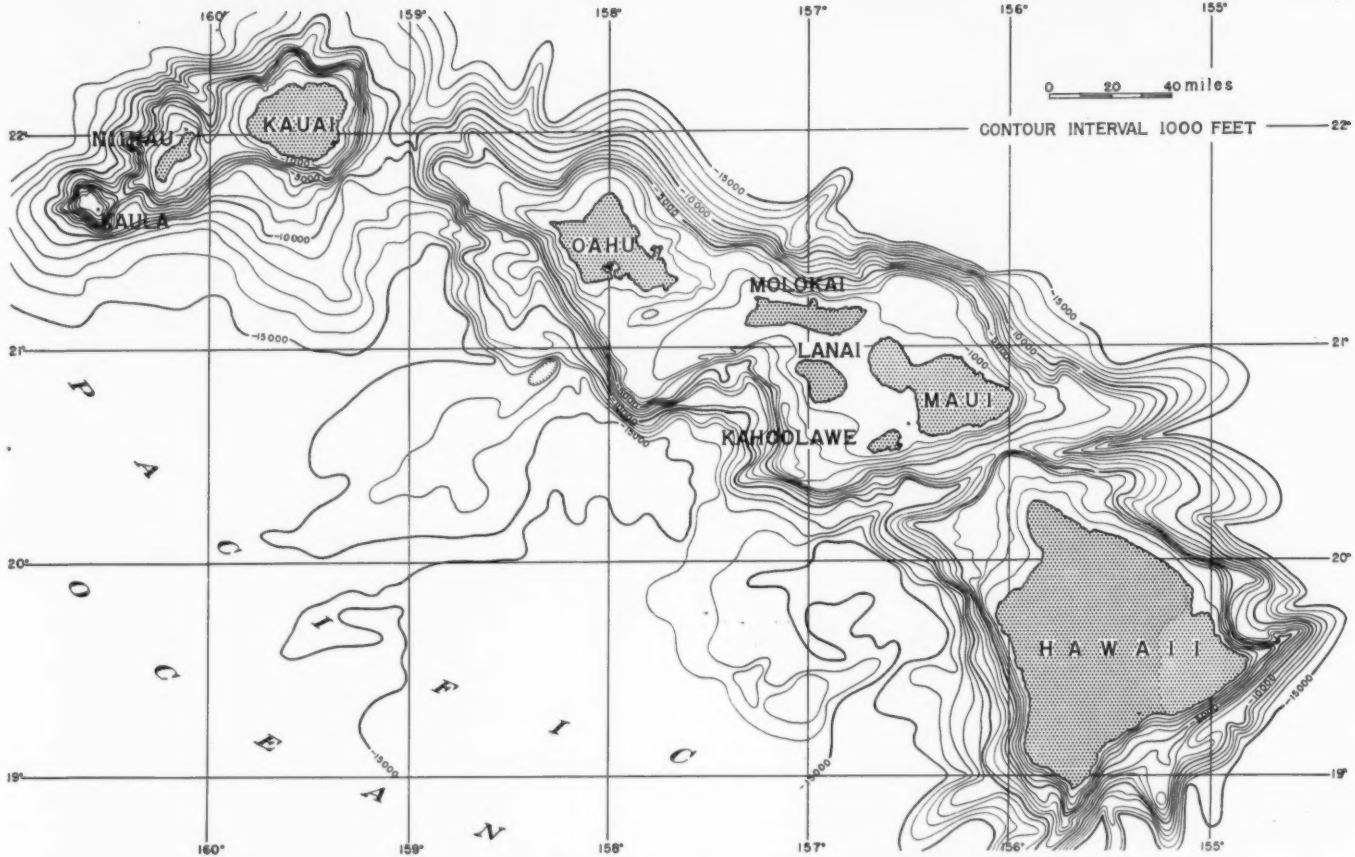



PLATE 2. Map of the Hawaiian Islands, showing submarine topography (after H. T. Stearns).

PLATE 3A. Wreckage left by the tsunami along Kamehameha Avenue, Hilo. Buildings on the left-hand (seaward) side of the street have been pushed into the street, some more or less intact, others as heaps of debris. Photo by Francis Lyman.

PLATE 3B. House in Keaukaha, east of Hilo, carried inland about 100 feet by the waves. The house in the background was above the reach of the water. Photo by G. A. Macdonald.

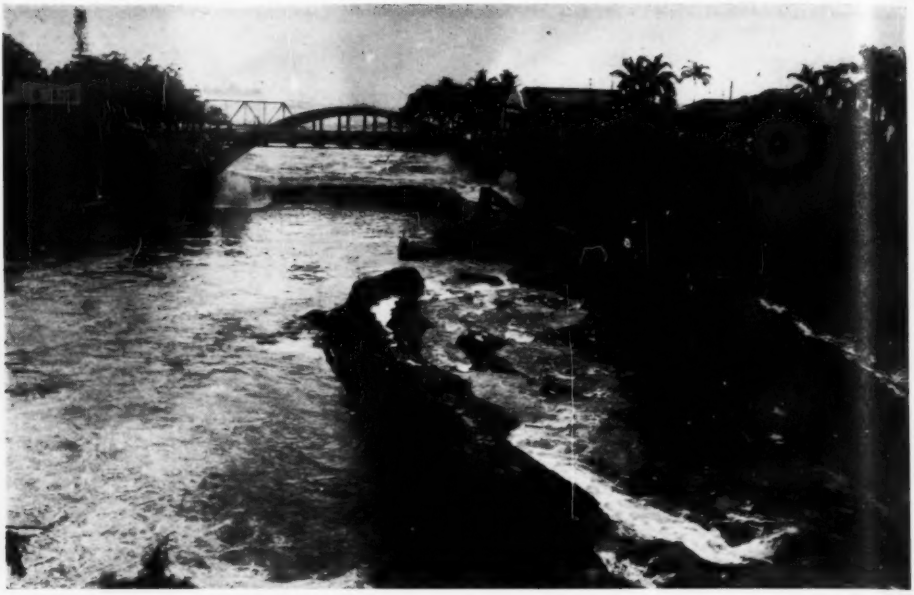


PLATE 4A. Mouth of the Wailuku River at Hilo, showing the advance of one of the later waves into the river mouth. Photo taken near the trough between two waves, showing very low water, and the waves starting up the river as the next crest approaches. The steel span from the distant railroad bridge is visible in the middle distance. Photo by Francis Lyman.

PLATE 4B. A minute or so later, the waves are sweeping turbulently up the river. Photo by Francis Lyman.

PLATE 5A. The very high stage of the water, in Wailuku River at Hilo, reached 3 or 4 minutes later than the stage shown in Plate 4B. Photo by Warren Flagg.

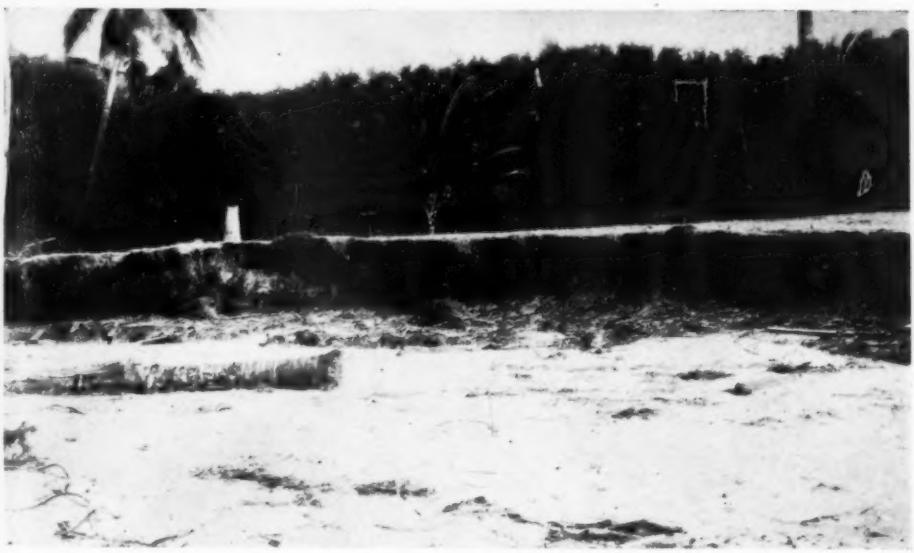


PLATE 5B. Scarp 5 feet high cut by the tsunami at the head of the beach at Moloaa, Kauai. The roots were exposed by removal of the enclosing soil. Photo by G. A. Macdonald.

PLATE 6A. Railroad track swept inland from its bed at Waialee, Oahu. Photo by U. S. Navy.

PLATE 6B. Coral heads thrown up on the beach at Kaaawa, Oahu, by the tsunami. Photo by G. A. Macdonald.

PLATE 7A. Grove of pandanus trees pushed over, and blocks of coral thrown up on the shore platform by the tsunami near Haena, Kauai. Photo by F. P. Shepard.

PLATE 7B. Small boat washed inland and left stranded by the tsunami near Pier 1, Hilo. Photo by G. A. Macdonald.

PLATE 8. Bore advancing past the railroad bridge at the mouth of the Wailuku River, Hilo. Note the steep front, the turbulence of the water behind it, and the placidity of the water in front of it. Photo by Shigeru Ushijima.

FIG. 7. Map of the island of Hawaii, showing heights (in feet above lower low water) reached by the water during the tsunami of April 1, 1946.

in the small bay just south of Hanamaulu Bay, on the eastern shore of Kauai, the water rose only 25 feet on the bay sides, but swept up the small valley at its head to a height of 40 feet. At Moloaa, on Kauai, the water reached an altitude of 40 feet in the axis of the valley, but only 30 to 35 feet on the bay walls. Again, at Honouliwai, on Molokai, the water reached a height of 27 feet opposite the beach, but went 6 feet higher up the valley. These are merely specialized examples of effect, upon the rush of water up on shore, of a topography above sea level which served to concentrate the inrushing water.

*Merging of waves from different directions.* —Wave crests traveling by different routes may arrive at a given locality simultaneously, giving rise to a wave of greater size than either. Likewise, the simultaneous arrival by different routes of a wave crest and a wave trough may effectually cancel out both. Thus, variations in the size and intensity of waves, particularly on the sides of the islands away from the wave origin, may result from the arrival, either in or out of phase, of two wave trains. During the tsunami of 1946 several examples of the formation of a large wave by the juncture of two smaller ones were observed. Thus, in the Keaukaha area east of Hilo, witnesses described the arrival of a wave from the north simultaneously with one from the northeast, which built up a very high crest at the place of juncture. At the head of Maunalua Bay, on the southeastern shore of Oahu, two waves were seen to advance up channels across the wide reef, move toward each other parallel with the shore, and meet, throwing water upward like the spray from a geyser. The water dashed up on shore to a height of only 3 feet except at the place of juncture, where it swept over the top of a sandspit 5 feet above sea level.

Progressively southward around the shores of Kauai, the average height of the high-water marks gradually decreases, and along much of the southern shore it is 6 to 12 feet above sea level. However, in a zone 3 or 4 miles wide it ranges from 15 to 18 feet. This zone is almost directly across the island from the direction of wave origin, and probably represents the area in which the waves refracted around opposite sides of the island met and reinforced each other.

## DAMAGE BY THE TSUNAMI

Damage by the tsunami can be divided into structural damage, damage by erosion and deposition, and damage by flooding. The total property damage has been estimated by the office of the Governor, Territory of Hawaii, at about $25,000,000. Space permits only a brief review of the types of damage. The numbers of dwellings destroyed and damaged by the tsunami on the major islands are listed in Table 2 on page 36.

Structural damage includes damage to buildings, roads, railroads, bridges, piers, breakwaters, fishpond walls, and ships. Frame buildings at low altitudes along Hawaiian shores suffered extensive damage. Some were knocked over, by the force of the waves, by cutting away of the sand on which they stood, or by destruction of the foundations. Others were bodily washed away from their foundations. Some had walls pushed in by the force of the water, and in a few residences the water went on through the house and took out the opposite wall. As with earthquakes, there was a tendency to reduce the few two-story buildings to a single story, by destruction of the lower story. It is noteworthy that houses which were well built and tied together internally could be moved for considerable distances without suffering severe damage. Even more striking was the fact that houses elevated on stilts a foot to several feet above the ground survived the waves much more effectively than did those built directly on the ground. Apparently the water was able to pass under such houses without greatly disturbing them, unless it was deep enough actually to float

the house off the stilts. The few reinforced concrete structures in devastated areas suffered little or no damage except that caused by flooding.

The railroads along the northern coast of Oahu and in Hilo were wrecked, partly through destruction of the roadbed, but largely because the tracks were shifted off the roadbed, either inland or shoreward. Locally rails were torn loose, but more generally the track was moved en masse, a motion probably aided by the buoyancy of the ties. Coastal highways also were partly destroyed, largely by undercutting as the water returned seaward, but partly by the direct force of the waves. Several highway and railway bridges were destroyed. Most appear to have been partly or entirely lifted from their foundations by the rising of the water under them. The head of the pier at Waianae, Oahu, was damaged in the same manner. At the Wailuku River, in Hilo, an entire span of the steel railroad bridge was torn loose and carried 750 feet upstream, passing under but not damaging a highway bridge. At Kolekole Stream, 11 miles farther north, an entire leg of the high steel railroad trestle was removed and carried upstream about 500 feet.

Part of the end and much of the shed of Pier 1 in Hilo was wrecked by the force of the wave. Most of the damage on Pier 2, however, resulted when heavy pontoons, which had been moored near by, were washed across the pier. The wharves at Kahului on Maui were flooded, but sustained little structural damage.

The upper part of the breakwater at Hilo was about 61 per cent destroyed (Plate 1). Blocks of rock weighing more than 8 tons were lifted off the breakwater and dropped both inside and outside it. Destruction was limited, however, to the part above water or that only slightly submerged. The average depth of water over the destroyed sections after the wave was only about 3 feet. The breakwater at Kahului, Maui, also suffered minor damage. At both Hilo and Kahului the breakwaters appear to have reduced materially the height and violence of the waves in the enclosed portions of the harbors.

Many small boats were washed ashore and damaged. Railroad cars were overturned on Oahu, Maui, and Hawaii. Many automobiles were wrecked. The loose stone walls of fishponds along the southern coast of Molokai were partly thrown down. The mill of the Hakalau Sugar Company, situated only about 10 feet above sea level at the mouth of Hakalau Gulch on the island of Hawaii, suffered severe damage.

Erosion by the tsunami resulted in the partial removal of some sand beaches, in some places causing a retreat of the shore line for several tens of feet, cutting of small scarps, and forming of large beach cusps at the heads of beaches; locally, erosion caused stripping away of a small amount of soil. The erosion was largely concentrated high on the beach, several feet above sea level. Some of the sand from the beaches was carried inland and redeposited. At Haena, Kauai, the highway was buried under 4 feet of sand, and thinner layers of sand covered roads on Oahu.

Flooding caused much water damage to house furnishings and personal property.

### LOSS OF LIFE AND PERSONAL INJURY

The following table summarizes, by islands, the number of persons killed, injured, or missing as a result of the tsunami. The figures were supplied by the American Red Cross. Most of the deaths were by drowning. By far the heaviest toll was at Hilo, with 83 known dead and 13 missing. Those listed as missing have been missing for more than 2 months, and must be presumed dead, bringing the total number of probable dead to 159. Great as it was, this loss of life was moderate compared to that in some other tsunamis, such as that of 1896 in the Sanriku

district in Japan, which took more than 27,000 lives (Byerly, 1942: 72).

TABLE 2

LIST OF CASUALTIES DURING THE TSUNAMI OF APRIL 1, 1946

| ISLAND | KNOWN DEAD | MISSING | INJURED* | HOMES DEMOLISHED† | HOMES DAMAGED† |
|---|---|---|---|---|---|
| Hawaii | 87 | 34 | 153 | 283 | 313 |
| Maui | 9 | 5 | 2 | 65 | 144 |
| Oahu | 9 | 0 | 0 | 67 | 335 |
| Molokai | 0 | 0 | 0 | 13 | 14 |
| Kauai | 10 | 5 | 8 | 60 | 130 |
| Total | 115 | 44 | 163 | 488 | 936 |
| | 159 | | | | |

* Injury sufficiently serious to require hospitalization.
† Homes only; other buildings not included. Data from Lewers and Cooke, Ltd.

## MITIGATION OF DISASTERS RESULTING FROM FUTURE TSUNAMIS

There is no Hawaiian shore which is exempt from tsunamis. The most likely sources of devastating tsunamis are the North Pacific and South America. The areas heavily hit by the 1946 tsunami are probably those most likely to be hit hard again by tsunamis from the North Pacific. Violent tsunamis from Central or South America might, however, cause much more damage than did the 1946 tsunami along eastern and southern coasts. There is also possibility of serious damage on western shores by a tsunami from Japan, particularly if the tsunami occurred during a heavy southwesterly storm. Tsunamis of local origin might do heavy damage on any shore.

It is obviously impractical to consider the removal of all dwellings from Hawaiian shores because of the danger from tsunamis. It might, however, be advisable to prevent or restrict building in certain areas of greatest danger, particularly in centers of heavy population, such as the waterfront at Hilo. Construction of suitable sea walls might also be advisable in places. Sea walls cannot, however, be built high and strong enough to hold the water back completely, and an open zone should be left back of the wall in which the water pouring over the wall can use up its energy in turbulence. Any construction permitted in such areas should be of a wave-resistant type, such as reinforced concrete. These wave-resistant buildings would have the added virtue of serving as a line of defense for frailer structures behind them. Frame structures in rural areas should be built up off the ground, and far enough back from the edge of the beach to reduce the danger of undercutting. They should also be properly reinforced and tied together.

It appears inevitable that future tsunamis will cause loss of property on Hawaiian shores, but loss of life from all except tsunamis of local origin could be largely or entirely avoided. A system of stations could be established around the shores of the Pacific and on mid-Pacific islands, which would observe either visually or instrumentally the arrival of large long waves of the periods characterizing tsunamis. The arrival of these waves should be reported immediately to a central station, whose duty it would be to correlate the reports and issue warnings to places in the path of the waves. It should be possible in this way to give the people of the Hawaiian Islands enough warning of the approach of a tsunami to permit them to reach places of safety. The effectiveness of the warning, however, would depend on education of the public on the necessity for leaving areas of danger, and on the efficiency of the local organization in spreading the warning and evacuating the threatened areas. Eventually it should also be possible to state, at the same time, which areas are likely to suffer the most damage. Before that can be done, however, we need more knowledge of the behavior of tsunamis on Hawaiian shores, particularly tsunamis from sources in the eastern and western Pacific, and a more complete picture of the submarine topography around the Hawaiian Islands.

SUMMARY

The tsunami which reached the shores of the Hawaiian Islands on April 1, 1946, was the most destructive in the history of the islands. Generated by a sudden shifting of the sea bottom on the northern slope of the Aleutian trough, the waves traveled southward to Hawaii with an average speed of 490 miles an hour, an average wave length of about 122 miles, and a height over the deep ocean of about 2 feet. Effects on Hawaiian shores varied greatly. Locally the water dashed more than 50 feet above sea level and swept as much as half a mile inland. Elsewhere the rise in water level was very small, and waves were gentle. Property damage was heavy but loss of life was moderate.

The heights and intensities of the waves at different points were influenced by position on the island toward or away from the source of the waves, offshore submarine topography, presence or absence of coral reefs, shore-line configuration, mutual reinforcement or interference by waves traveling different paths, and the presence or absence of storm waves. Loss of property during future tsunamis can be reduced by proper construction, by erection of sea walls, and by restricting or prohibiting construction in certain especially dangerous areas. Loss of life can be nearly or entirely eliminated by the establishment of a suitable system for warning of the approach of waves.

## REFERENCES

BODLE, R. R. Note on the earthquake and seismic sea wave of April 1, 1946. *Amer. Geophys. Union Trans.* 27: 464–465, 1946.

BYERLY, PERRY. *Seismology.* x+256 p., 58 fig. Prentice-Hall, New York, 1942.

GREEN, C. K. Seismic sea wave of April 1, 1946, as recorded on tide gages. *Amer. Geophys. Union Trans.* 27: 490–500, 1946.

GREEN, GEORGE. On the motion of waves in a variable canal of small depth and width. *Cambridge Phil. Soc. Trans.* 6: 457–462, 1838.

GUTENBERG, BENO, and CHARLES F. RICHTER. *Seismicity of the earth.* 131 p., 17 fig. Geol. Soc. Amer. Spec. Paper 34. New York, 1941.

IMAMURA, AKITUNE. *Theoretical and applied seismology.* 358 p. Tokyo, 1937.

JAGGAR, THOMAS A., JR. Hawaiian damage from tidal waves. *Volcano Letter* 321: 1–3, 1931.

POWERS, HOWARD A. The tidal wave of April 1, 1946. *Volcano Letter* 491: 1–3, 1946.

SHEPARD, FRANCIS P., GORDON A. MACDONALD, and DOAK C. COX. The tsunami of April 1, 1946. [In preparation.]

UNITED STATES NAVY HYDROGRAPHIC OFFICE. *Breakers and surf.* 52 p., 19 fig., 4 pl. U. S. Navy Hydrog. Off. Pub. 234. Washington, D. C., 1944.

# Dolomitization in Semi-arid Hawaiian Soils[1]

G. Donald Sherman, Yoshinori Kanehiro, and
Charles K. Fujimoto[2]

## INTRODUCTION

Soils developed under a limited rainfall usually show the influence of salinization by calcium or sodium salts. In the presence of appreciable quantities of sodium salts, soil carbonates are converted to sodium carbonate and give rise to a condition known as black alkali. Recently workers have found soils in which the salinization had been caused by magnesium salts. Ellis and Caldwell (1935) found a magnesium clay "solonetz" in certain Manitoba soils in which 80 to 90 per cent of the adsorbed cations were calcium and magnesium. In addition, the calcium-to-magnesium ratio in these soils varied from 1.6 to 1.0. Alicante (1933) reported a Philippine soil which contained twice as much magnesium as calcium in a soluble form. Kudrin and Rozanov (1938), working with "sierozem" soils, found a high content of adsorbed magnesium especially in the "solonchaks." Rost and Chang (1941) divided the solonchaks of the Red River Valley of Minnesota into two groups: those having 20 to 50 per cent of their exchangeable cations as magnesium and those having more than 85 per cent of their exchangeable cations as calcium. In addition, they found a direct relation between exchangeable magnesium and gypsum in the soil. Thus, there is evidence that magnesium salts may play an important role in the salinization processes in soil.

Salinization of a soil with magnesium salts would be expected to give rise to the formation of magnesium carbonate, a very insoluble compound of magnesium. However, if a magnesium sulfate salinization occurred in a soil rich in calcium carbonate, then dolomitization might occur in the soil with the formation of two relatively insoluble compounds, dolomite (double carbonate of calcium and magnesium) and gypsum. The results of some recent studies suggest that this process does occur in soils. Alway and Zetterberg (1935) found that the molecular ratio of calcium carbonate to magnesium carbonate varied from 1.51 to 4.80 in calcareous Minnesota soils. Later work on Minnesota soils (Sherman, 1937) showed the occurrence of dolomitization in soils which have a high water table of waters rich in magnesium sulfate. In some of these soils the molecular ratio of calcium carbonate to magnesium carbonate approached 1.0. The carbonates in the dolomitized area did not visibly effervesce when treated with cold dilute hydrochloric acid even though the soils contained as much as 40 per cent carbonates. When pure dolomite is treated with cold dilute hydrochloric acid, the ensuing effervescence is barely perceptible. This relative inaction of a carbonate to cold hydrochloric acid is characteristic of dolomite. The carbonates from the area rich in magnesium were identified as dolomite and distinguished from calcite and other carbonates by a stain technique (Sherman and Thiel, 1939). Pellets containing gypsum and long needle-like crystals of gypsum were found imbedded in the clay below the dolomitized layer of soil. The nature of the occurrence of gypsum in these forms suggested their secondary origin.

[1] Published by permission of the Director of the University of Hawaii Agricultural Experiment Station as Technical Paper 137.

[2] University of Hawaii Agricultural Experiment Station, Honolulu, Hawaii.

In Hawaii, Lyman and Dean (1938) have reported soils containing twice as much magnesium as calcium. They found these soils in low-lying areas which had been under salt water in the past. The authors have found other Hawaiian soils rich in magnesium in areas which had never been under sea water. These soils in general occur only in the dry areas of the Hawaiian Islands.

The dark gray soils of Lualualei Valley, Waianae Valley, and Makaha Valley on the west slope of the island of Oahu have a low calcium-to-magnesium ratio, as shown in the present study. Under a very limited annual rainfall of 16 to 20 inches per year, these soils were developed on alluvial materials brought down from the Waianae Range. These soils are intermingled with numerous outcrops of coral rock (95 per cent calcium carbonate) and a few outcrops of basaltic rocks. The soils developed on these materials (coral and basaltic rock) can be readily distinguished from the alluvial soils by color. The native vegetation in the area is that characteristic of semi-arid regions, the dominant vegetation being algarroba (mesquite). Because of the highly dispersed condition of the soil and the consequent retarded penetration of water, the "A" and "B" horizons of the soil profile have been very poorly developed. Crystals of gypsum were found in some of the subsoils. In soil above the layer containing gypsum, the carbonates gave a very weak effervescence when treated with cold dilute hydrochloric acid and a violent effervescence with hot acid. This test would indicate the presence of dolomite in this soil.

The object of this study is to determine whether dolomitization is taking place, and if so, to what extent it is occurring in these soils and its possible relationship to soil-forming processes.

## EXPERIMENTAL METHODS

Soil samples from several areas of soils having a high percentage of their exchangeable cations as magnesium were collected, on the basis of profiles which showed evidence of dolomitization. These samples were analyzed for water-soluble salts, for exchangeable cations, and for the composition of the carbonates.

1. Water-soluble salts were leached from the soil by shaking 25 grams of soil with a liter of distilled water and allowing the mixture to stand overnight. It was then filtered on a Buchner funnel and the soil was washed with another liter of distilled water or until no test was given for sulfates in the leachate. The filtrate was evaporated to a small volume and the organic matter was destroyed by acid oxidations with a few drops of hydrogen peroxide. Calcium was determined by the standard volumetric method, using potassium permanganate as the oxidizing agent. Magnesium and sulfate were determined gravimetrically as magnesium pyrophosphate and barium sulfate, respectively.
2. Exchangeable cations were extracted by neutral normal ammonium acetate solution containing 70 per cent ethyl alcohol to reduce the solubility of the calcium carbonate. Calcium and magnesium were determined by the same methods as were used for the water-soluble ions. Potassium was determined volumetrically by the cobaltinitrite method (Volk and Truog, 1934), and sodium was determined gravimetrically as sodium zinc uranyl acetate (Barber, 1928).
3. The carbonate analysis was made by a method described for the analyses of dolomitic carbonates (Sherman, 1937). This method involved the determination of carbonate carbon dioxide by decomposing the carbonates with normal hydrochloric acid solution, followed by absorption of the carbon dioxide in a 0.5 N sodium hydroxide solution in an absorption tower. Before entering the tower, the carbon dioxide was passed through a silver sulfate-sulfuric acid solution to remove any hydrochloric acid fumes from the digestion flask. The digestion flasks were heated to boiling in order to insure the complete decomposition of the dolomite. After the decomposition of the carbonates, the sodium hydroxide solution in the absorption tower was drained into a volumetric flask. The tower was washed with five portions of hot carbon-dioxide-free distilled water to remove all the sodium hydroxide. The carbonates were precipitated in the volumetric flask by the addition of barium chloride and the solution was then made up to volume. The precipitate was allowed to settle and an aliquot was taken from the clear portion of the liquid. The excess sodium hydroxide was determined in the aliquot

by titration with a standard acid. A blank determination was made by the same method, using only the chemical reagents.

To determine the composition of the carbonates, another sample of soil was extracted with the amount of half-normal hydrochloric acid calculated as necessary to decompose the determined quantity of carbonates in the soil, this amount being based on carbonate-carbon dioxide determinations. To insure a slight excess of the acid, 0.1 ml. was added. Previous work has shown that only the carbonates are attacked by this quantity of acid (Sherman, 1937). The mixture was diluted with distilled water and then heated to boiling to insure the complete digestion of the carbonates. The mixture was filtered and the soil washed free of chloride with hot distilled water. Calcium and magnesium were determined in the filtrate by using the usual standard methods for these elements.

## EXPERIMENTAL RESULTS

Samples of surface soils were collected from various parts of Lualualei Valley, Waianae Valley, and Makaha Valley on the island of Oahu, and in Table 1 is given the content of exchangeable calcium and magnesium in these soils. In every soil, magnesium constituted a very appreciable part of the cations, accounting for 20 to 45 per cent of the total exchangeable cations present in the soil.

Samples from a soil profile representing a typical area which showed indications of dolomitization were analyzed for composition of the water-soluble salts, quantity of each exchangeable cation, and composition

### TABLE 1

THE CONTENT OF EXCHANGEABLE CALCIUM AND MAGNESIUM IN SURFACE SOILS FROM MAKAHA VALLEY, WAIANAE VALLEY, AND LUALUALEI VALLEY ON THE ISLAND OF OAHU

| LOCATION OF SOIL | pH | EXCHANGEABLE Ca | EXCHANGEABLE Mg | RATIO Ca:Mg |
|---|---|---|---|---|
| | | m.e./100 gm. | m.e./100 gm. | |
| Makaha Valley | 7.3 | 22.12 | 16.06 | 1.38 |
| Waianae Valley | 7.1 | 24.15 | 19.69 | 1.23 |
| Lualualei Valley | 7.4 | 39.36 | 13.62 | 2.90 |
| | 6.3 | 27.40 | 14.21 | 1.93 |
| | 6.9 | 27.38 | 19.05 | 1.44 |
| | 7.3 | 36.80 | 14.69 | 2.50 |
| | 7.3 | 40.00 | 14.79 | 2.70 |
| | 7.1 | 56.80 | 16.15 | 3.49 |
| | 6.4 | 29.40 | 18.62 | 1.58 |
| | 6.9 | 31.98 | 19.16 | 1.67 |
| | 7.0 | 26.10 | 17.77 | 1.47 |
| | 7.8 | 33.89 | 9.89 | 3.43 |
| | 7.6 | 37.42 | 9.64 | 3.88 |

### TABLE 2

THE COMPOSITION OF THE WATER-SOLUBLE SALTS OF A LUALUALEI VALLEY SOIL WHICH CONTAINS DOLOMITIC CARBONATES

| DEPTH OF SOIL SAMPLES | pH | WATER-SOLUBLE SALTS M.E. PER 100 GM. SOIL | | | RATIO Ca:Mg |
|---|---|---|---|---|---|
| | | Ca | Mg | $SO_4$ | |
| inches | | | | | |
| 0–6 | 7.8 | 0.84 | 0.43 | 0.52 | 1.95 |
| 6–12 | 7.7 | 0.76 | 0.43 | 0.36 | 1.77 |
| 12–18 | 7.5 | 0.72 | 0.48 | 0.40 | 1.50 |
| 18–24 | 7.5 | 0.80 | 0.41 | 0.41 | 1.95 |
| 24–30 | 7.2 | 8.48 | 2.18 | 10.10 | 3.89 |
| 30–36 | 7.3 | 26.60 | 3.63 | 30.12 | 7.33 |
| 36–42 | 7.3 | 26.78 | 4.36 | 31.08 | 6.14 |

of the carbonates. The soil at a depth of 24 inches and deeper contained grains and needle-like crystals of gypsum. The carbonates in the soil above the zone of gypsum accumulation effervesced weakly when treated with cold dilute hydrochloric acid; this fact suggested the possibility that a high percentage of the total carbonates was in the form of dolomite. The data obtained in the analysis of this profile were similar to those obtained from similar soil profiles.

The data in Table 2 were obtained in the analysis of the water-soluble salts extracted from the soil samples of the selected profile. The greatest quantity of water-soluble salts was found in the part of the profile which contained the crystalline gypsum. The calcium and sulfate amounted to approximately 27 and 31 milliequivalents per 100 grams in this horizon. The water-soluble magnesium increased with the increase in sulfate but the increase was less than that shown by the calcium. The milliequivalents of water-soluble calcium and magnesium were equal to the milliequivalents of sulfate in soils rich in sulfate. This would suggest that both calcium and magnesium were combined with the sulfate in this part of the profile. The lowest calcium-to-magnesium ratio was found in the zone overlying the zone of gypsum accumulation.

In Table 3 are given the data obtained for the quantities of exchangeable cations in the soil from the different parts of the soil profile. The quantity of exchangeable calcium was found to be markedly greater in the soils from the part of the profile which showed the accumulation of gypsum. In this part of the profile, calcium amounted to 80 to 90 per cent of the total exchangeable cations in the soil, whereas in the soil above the zone of gypsum accumulation it amounted to 72 per cent of the total exchangeable cations. Exchangeable magnesium showed an opposite relationship, since it amounted to 25 per cent of the total exchangeable bases in the soils of the profile above the zone of gypsum accumulation and in the gypsum zone it accounted for 9 per cent of the cations. The ratio of exchangeable calcium to magnesium was the lowest in the soils above the zone of gypsum accumulation. The quantity of exchangeable potassium and sodium found in the soils of this profile was small, amounting to less than 4 per cent of total exchangeable cations.

The results of the analysis of the carbonate fraction are given in Table 4. The amount of total carbonates found in any soil horizon of this profile was not great. Analysis of carbonates in the soils of this area has failed to show a zone of carbonate accumulation in

TABLE 3

THE QUANTITY OF EXCHANGEABLE CATIONS AND THE PERCENTAGE OF EACH CATION OF THE TOTAL EXCHANGEABLE CATIONS IN A LUALUALEI VALLEY SOIL WHICH CONTAINS DOLOMITIC CARBONATES

| DEPTH OF SOIL SAMPLES | EXCHANGEABLE CATIONS IN M.E. PER 100 GM. | | | | | RATIO Ca:Mg | PERCENTAGE OF TOTAL EXCHANGEABLE CATIONS | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Exchange capacity | Ca | Mg | K | Na | | Ca | Mg | K | Na |
| inches | | | | | | | | | | |
| 0–6 . . | 65.8 | 48.0 | 15.8 | 1.4 | 0.6 | 3.04 | 72.9 | 24.0 | 2.1 | 1.0 |
| 6–12 . . | 57.2 | 40.8 | 14.5 | 1.0 | 0.9 | 2.81 | 71.3 | 25.3 | 1.7 | 1.6 |
| 12–18 . . | 54.9 | 39.3 | 14.2 | 0.5 | 0.9 | 2.78 | 71.6 | 25.9 | 0.9 | 1.6 |
| 18–24 . . | 48.0 | 34.5 | 12.1 | 0.3 | 1.1 | 2.85 | 71.8 | 25.2 | 0.6 | 2.3 |
| 24–30 . . | 52.2 | 42.5 | 8.2 | 0.3 | 1.2 | 5.18 | 81.4 | 15.7 | 0.6 | 2.3 |
| 30–36 . . | 74.4 | 66.4 | 6.5 | 0.2 | 1.3 | 10.21 | 89.2 | 8.7 | 0.3 | 2.0 |
| 36–42 . . | 76.1 | 67.4 | 7.2 | 0.2 | 1.3 | 9.36 | 88.6 | 9.4 | 0.3 | 1.7 |

any soil profile. In this profile, magnesium carbonate was found in the greatest quantities in the soils above the zone of gypsum accumulation. The portion of carbonates in the form of dolomite was found to be greatest in the 12- to 18-inch layer of soil, which corresponded to the zone of weakest effervescence with cold dilute hydrochloric acid. The molecular ratio of calcium carbonate to magnesium carbonate was 1.12 for this layer. The carbonates were considered to be in the form of dolomite, since if they were a mixture of calcium and magnesium carbonates the quantity of calcium carbonate present would have been sufficient to give a very violent effervescence with cold dilute acid. Sherman and Thiel (1939) found that when carbonates of the soil were 87 per cent or more dolomite they gave a characteristic effervescence with cold dilute acid which was similar to that given by pure dolomite. Approximately 94 per cent of the carbonates in this soil layer are in the form of dolomite. In the soil from the zone of gypsum accumulation, calcium carbonate constituted approximately 80 per cent of the total carbonates.

## DISCUSSION

This study has presented an instance of the dolomitization of a calcareous soil by the action of magnesium salts. The occurrence of dolomitization in soil, a process by which the double carbonate of calcium and magnesium is formed, has been established by chemical analysis of the soil carbonates, by weakness of effervescence of the carbonates when treated with cold dilute hydrochloric acid, and by the presence of one of the two end products of the process in the soil, gypsum. The formation of dolomite in these soils is associated with the soil-forming processes, since the materials which make up the alluvial parent material do not contain dolomite as a mineral. The soil is rich in magnesium silicate minerals and thus provides a source of magnesium as soil weathering progresses.

The mechanism by which the dolomite is formed may need some explanation, since calcium exceeds magnesium in both the water-soluble salts and exchangeable cations. The soils of this area receive most of their precipitation during very short intervals of

TABLE 4

THE COMPOSITION OF THE SOIL CARBONATES OF A LUALUALEI VALLEY SOIL WHICH CONTAINS DOLOMITIC CARBONATES

| DEPTH OF SOIL SAMPLES | $SO_4$ | PERCENTAGE SATURATION WITH Ca+Mg | CARBONATE ANALYSIS | | | | |
|---|---|---|---|---|---|---|---|
| | | | Effervescence in cold dilute HCl | Total carbonates | $MgCO_3$ | Carbonates as dolomite | Ratio Mols $CaCO_3$ to Mols $MgCO_3$ |
| inches | m.e./100 gm. | per cent | | gm. /100 gm. soil | gm. /100 gm. soil | per cent of total | |
| 0–6 . . | 0.52 | 96.9 | strong | 6.06 | 1.50 | 54.1 | 2.56 |
| 6–12 . . | 0.36 | 96.6 | weak | 4.62 | 1.35 | 63.9 | 2.03 |
| 12–18 . . | 0.40 | 97.5 | very weak | 3.44 | 1.47 | 93.9 | 1.12 |
| 18–24 . . | 0.41 | 97.0 | weak | 0.87 | 0.21 | 51.7 | 2.64 |
| 24–30 . . | 10.10 | 97.1 | strong | 0.84 | 0.09 | 23.8 | 6.82 |
| 30–36 . . | 30.12 | 97.9 | very strong | 2.55 | 0.23 | 19.6 | 8.60 |
| 36–42 . . | 31.08 | 98.0 | very strong | 3.67 | 0.28 | 16.6 | 10.27 |

the year. Each year these soils become very dry, often to the extent that they show wide and deep cracks. During these periods of drought the salts are brought toward the surface by capillary rise of water. In the process of drying, much of the calcium salt is precipitated at lower levels, while the magnesium salt, owing to its higher solubility, remains in solution. At such periods the soluble magnesium may exceed the soluble calcium and thus create conditions favorable to the formation of dolomite by the action of magnesium sulfate on calcium carbonate. When the soils become wet the salts are leached to a lower level in the soil, from which the more soluble salts (magnesium) can rise again. This would be a possible explanation of the gypsum accumulation in the subsoil of these soils and of the formation of dolomite directly above the gypsum layer.

The formation of dolomite and gypsum as end products of this process should be expected under arid or semi-arid conditions, since these two compounds represent the most insoluble compounds of calcium and magnesium which could be formed in the presence of calcium carbonate. According to Leather (1913), the presence of magnesite together with calcite in soil is extremely doubtful and if magnesite did exist it would only be present in traces. It has been found that when the dolomitic carbonates are treated with acid they give up calcium and magnesium carbonate in approximately a 1:1 ratio. This fact and the effervescence which is characteristic of dolomite establish the identity of the type of carbonate formed. The formation of gypsum will result from the action of magnesium sulfate on the calcium carbonate and its precipitation from solution during wetting and drying of the soil. This process would lead to the formation of gypsum in the crystalline forms found in these soils.

Dolomitization in soils can be expected to occur under soil conditions similar to those described in this report. It is likely that dolomitization has occurred to some extent in many calcareous soils.

## CONCLUSIONS

As a result of this study of the composition of the soil carbonates in a representative soil profile from Lualualei Valley, Makaha Valley, and Waianae Valley, the following conclusions may be drawn:

1. Dolomitization of the carbonates has been established by the chemical composition of the soil carbonates, by the effervescence in cold dilute hydrochloric acid characteristic of dolomite, and by the presence of one of the two relatively insoluble end products, gypsum, which will be produced when this process occurs in the presence of sulfates and calcium carbonate.
2. In the soil horizons where dolomitization has occurred, 50 to 94 per cent of the carbonates are in the form of dolomite.
3. In order that the process of dolomitization may occur, the presence of soluble magnesium salts is required. The soils of this area were found to be rich in magnesium, since this cation accounted for 20 to 45 per cent of the exchangeable cations in the soil. The drying of the soil during dry weather concentrates and increases the soluble magnesium until it exceeds the calcium in solution due to the precipitation of calcium as gypsum, and thus leads to conditions favorable to the formation of dolomite. Periodic rainy and dry seasons are essential to the dolomitization process.
4. The soil below the zone where the dolomitic carbonates exist contained numerous pellets filled with crystalline gypsum and crystals of gypsum. In this zone of gypsum accumulation the calcium-to-magnesium ratio is very high.

## REFERENCES


ALICANTE, M. M. A survey of the soils in the district of the Philippine Milling Company, Mindoro. *Philippine Sugar Assoc. Res. Bur., Ann. Rpt. Dir., 1933:* 69–72, 1933.

ALWAY, F. J., and JEAN M. ZETTERBERG. Relative amounts of calcium carbonate and magnesium carbonate in some Minnesota subsoils. *Soil Sci.* 39: 9–14, 1935.

BARBER, H. H., and I. M. KOLTHOFF. A specific reagent for the rapid determination of sodium. *Amer. Chem. Soc. Jour.* 50: 1625–1631, 1928.

ELLIS, J. H., and O. G. CALDWELL. Magnesium clay "solonetz." *Third Internatl. Cong. Soil Sci. Trans.* 1: 348–350, 1935.

KUDRIN, S. A., and A. N. ROZANOV. The characterization of serozems having a high content of adsorbed magnesium. *Pedology* (8): 836–855, 1938.

LEATHER, J. W. Soil problems. *Pusa Agr. Res. Inst. and Col., Sci. Rpts., 1913–14:* 16–17, 1913. [Abstract, *U. S. Off. Expt. Stas., Expt. Sta. Rec.* 33: 513, 1915.]

LYMAN, CLARENCE, and L. A. DEAN. The calcium-magnesium ratio of some Hawaiian soils. *Hawaii Univ. Agr. Expt. Sta. Rpt., 1938:* 49, 1938.

ROST, C. O., and P. C. CHANG. Exchangeable bases of solonchak of the Red River Valley. *Soil Sci. Soc. Amer. Proc.* 6: 354–359, 1941.

SHERMAN, G. DONALD. *The occurrence of dolomite in the subsoils of the Red River Valley.* [Master's thesis on file at University of Minnesota, 1937.]

——— and G. A. THIEL. Dolomitization of glacio-lucustrine silts of Lake Agassiz. *Geol. Soc. Amer. Bul.* 50: 1535–1552, 1939.

VOLK, N. J., and E. TRUOG. A rapid chemical method for determining the readily available potash of soils. *Amer. Soc. Agron. Jour.* 26: 537–546, 1934.

# Notes on the Red-billed Leiothrix in Hawaii

HARVEY I. FISHER and PAUL H. BALDWIN[1]

THE NAME JAPANESE HILL ROBIN often used in Hawaii for *Leiothrix lutea* (Scopoli) is an unfortunate misnomer, as is Pekin Nightingale, because the bird does not occur in the wild in Japan nor does it occur as far north as Shanghai, much less Pekin or Peiping.

Henshaw (1911: 63) recommended the introduction of this species into Hawaii as early as 1911 and noted that it lives to some extent on insects and small fruits. Caum (1933: 38–39) states that the species was first introduced into the Territory of Hawaii in 1918 by Mrs. Dora Isenberg, who liberated several birds on the island of Kauai. However, the records kept by the Territorial Board of Agriculture and Forestry indicate several small importations previous to this time (Table 1). These probably were made for cage purposes, but some of the long-time residents believe *Leiothrix* was established in the Hawaiian Islands before 1918 by escapees from cages.

In Table 1 are summarized all importations of the species shown by official records. It is worthy of note that the table does not include the importations of 1918 and 1928 from San Francisco mentioned by Caum (*loc. cit.*). There may have been other unrecorded introductions. The table does show a total of 41 importations, including some 1,037 individuals. These individuals have been released on all the larger islands of the southeastern end of the Hawaiian Chain; the islands are Kauai, Oahu, Molokai, Maui, and Hawaii.

From official records the only indication

[1] Department of Zoology and Entomology, University of Hawaii, and Bernice P. Bishop Museum, Honolulu, respectively.

TABLE 1

PORTS OF EMBARKATION AND SUMMARY OF DATES AND NUMBERS OF *Leiothrix* IMPORTED INTO HAWAII

| YEAR | PORT OF EMBARKATION | | | | | TOTAL |
|---|---|---|---|---|---|---|
| | Hongkong | Sydney | Shanghai | Kobe | Yokohama | |
| 1911 | 1 | .... | .... | .... | .... | 1 |
| 1913 | 2, 6 | .... | .... | .... | 3 | 11 |
| 1915 | .... | .... | .... | .... | 4 | 4 |
| 1916 | 5 | 2 | .... | .... | .... | 7 |
| 1917 | .... | .... | .... | .... | 1, 4, 6, 3 | 14 |
| 1918 | .... | .... | .... | .... | 2 | 2 |
| 1919 | 2, 12, 12 | .... | .... | .... | .... | 26 |
| 1922 | 1 | .... | .... | .... | .... | 1 |
| 1923 | .... | .... | 3 | .... | .... | 3 |
| 1924 | .... | .... | 2 | .... | .... | 2 |
| 1928 | 3, 50 | .... | .... | 40, 30, 19 | .... | 142 |
| 1929 | .... | .... | .... | 6, 184 | .... | 190 |
| 1932 | .... | .... | .... | .... | 1 | 1 |
| 1933 | .... | .... | 1 | .... | 7 | 8 |
| 1934 | .... | .... | .... | 75 | .... | 75 |
| 1935 | .... | .... | .... | .... | 28 | 28 |
| 1936 | 1, 4, 1, 80 | .... | 200 | .... | 100, 37, 36 | 459 |
| 1937 | 1 | .... | 2 | .... | 60 | 63 |
| Totals | 181 | 2 | 208 | 354 | 292 | 1,037 |

we have of the original home of these introduced birds is the name of the port from which they were shipped, and this tells little. It was hoped that the subspecific determination of the Hawaiian birds might aid in revealing the native home of the introduced stock. However, H. G. Deignan, of the United States National Museum, has graciously examined 15 of our specimens from the Hawaiian Islands and has identified them as *Leiothrix lutea lutea.* The type locality of this race is the mountains of Anhwei Province south of the Yangtze. Since *lutea* ranges over all of China south of the Yangtze and east of the Kansu frontier, the original home of the breeding stock now in the Hawaiian Islands cannot be further specified.

### DISTRIBUTION IN THE HAWAIIAN ISLANDS

Caum (1933: 39) noted that large flocks were present on Kauai and rightly assumed that the birds were breeding successfully on that island. However, he was uncertain about the status of the species on other islands, simply saying that the birds were "reported" to be breeding on Molokai, Maui, and Hawaii and "believed" to be breeding on Oahu. Subsequent unpublished observations have indicated that the birds are reproducing and are increasing the extent of their ranges on Hawaii, Oahu, Molokai, Kauai, and Maui. The bird is abundant, widespread, and nesting successfully on Hawaii. It is numerous and nesting in the Koolau and Waianae mountain ranges on Oahu. In early June, 1945, adults were observed feeding nearly fledged young in the mountain valleys at Mapulehu, Molokai, at an elevation of 500 feet. On Maui it is generally present in the moderately wet to wet forests of Haleakala and probably West Maui.

The vertical distribution on individual islands is unrecorded except on Oahu, Molokai, Maui, and Hawaii, where we have observed the species. On Oahu the species ranges from 400 to 3,000 feet in the Koolau Range and probably goes to about 4,000 feet in the Waianae Mountains. In other words, its vertical distribution includes all elevations available except those below 400 feet, and it seems likely that the species might be found below this level if all suitable cover conditions in deep valleys were to be investigated. Although the altitudinal range is considerable, the birds are most abundant above 600 to 800 feet; this fact may be due to the lack of sufficient cover at lower elevations.

On Hawaii the bird has been found chiefly at elevations ranging from near sea level (Puna district and windward Hawaii) to 7,500 feet on Mauna Loa. We may assume that the upward limit of their livable range on Hawaii is between 8,000 and 9,000 feet. However, there is no definite upper limit to the distribution in fall and early winter, when the birds band together and wander all over the island. Flocks have frequently been seen at more than 13,500 feet on Mauna Loa, but these flocks are soon reduced by deaths caused by exposure and starvation.

Temperature may be a factor in limiting upward distribution; this is indicated by increased mortality rates above 9,000 feet on Hawaii, where the mean temperature is 40° to 50° F. with but little seasonal variation. However, it is not likely that temperature is the important factor below this altitude, and even above 9,000 feet, food, wind, and cover conditions are probably the more important limiting factors.

Throughout its range (vertical and horizontal) the species is limited to the more moist, forested areas having a dense understory of plant growth. On Oahu this means it is restricted to the mountain valleys; seldom is the bird observed on the higher ridges except during its movements from one valley to another. Despite the bird's proclivity for moist valleys, rainfall apparently is not the determining factor except possibly in areas having less than 40 inches a year, for yearly

averages of precipitation in its observed range on Oahu vary from 30 to 200 inches. On Hawaii the species is rare or absent in areas having less than 20 inches a year; this is true in the leeward districts. In the Kau district, where rainfall is 20 inches or less in much of the lowland, *Leiothrix* is rare below 3,000 feet and absent below 2,500 feet. On Maui the annual rainfall in parts of the range of the species is 350 inches.

Presence or absence of surface water may be a significant factor. The species has often been observed bathing in water up to 2 inches in depth. Further, the birds are most frequently observed within a few hundred yards of such water. We have on several occasions noted birds drinking rain water caught in basins formed by the large fallen leaves of the ti plant (*Cordyline terminalis*) and the kamani tree (*Terminalia Catappa*).

### HABITAT IN THE HAWAIIAN ISLANDS

A cover of dense vegetation near the ground is the major characteristic of the habitat of *Leiothrix*. Without exception the birds are found in areas having such a growth. It seems immaterial whether or not a canopy is formed above this undergrowth, as long as there is a thicket 10 to 15 feet in depth. We have never found this species feeding, nesting, or even remaining long in the large plantings of imported ironwood (*Casuarina*) or exotic *Eucalyptus;* there is rarely any ground growth in such places. The birds are frequently found in guava (*Psidium Guajava*) thickets not having a high canopy.

On Oahu the species is most abundant in the dense understory of forested and partly forested areas on the floors and steep slopes of the valleys. Usually there is in this habitat a stream, a small pond, or some temporary catch basins (fallen leaves, concavities in rocks) to hold rain water. On the extremely steep slopes of Manoa Valley, Oahu, at 1,100 feet where the rainfall is between 100 and 150 inches annually is a "typical" habitat. Here are scattered ohia lehua (*Metrosideros collina* var. *polymorpha*) trees up to 12 and 15 feet in height, interspersed with koa (*Acacia Koa*) trees up to 30 feet high and with kukui nut (*Aleurites moluccana*) trees. These three kinds of trees form in many places a loose, open canopy. In certain areas the kukui trees form a dense canopy. The understory consists of ti plants (*Cordyline terminalis*) up to 8 feet in height, a few *Gardenia Remyi* trees, and an occasional white hibiscus (*Hibiscus Arnottianus*). The lowest-growing vegetation is made up chiefly of palm foxtail (*Setaria palmifolia*) and oi shrubs (*Stachytarpheta cayennensis*). This growth is in many places so dense that it is difficult to penetrate. A further factor in creating an almost impenetrable thicket is the presence near the ground of many fallen branches. Also, in a few places the intertwining branches of the hau tree (*Hibiscus tiliaceus*) add to the maze (Fig. 1).

FIG. 1. Thicket formed by branches of the hau tree (*Hibiscus tiliaceus*) in Nuuanu Valley, Oahu, at 1,000 feet elevation.

On Hawaii this babbler is most abundant in forests from 1,000 to 5,000 feet elevation and with 40 or more inches of rain each year. Forests with a variety of habitats, such as koa forest partly modified by cattle grazing and with thimbleberries (*Rubus rosaefolius*) and other fruiting plants, harbor large numbers of the species. The density reaches 80 to

100 birds an acre at times at Kipuka Puaulu (4,000 feet). Guava thickets at elevations of 1,000 to 2,000 feet are also tenanted in good numbers. However, virgin tree fern forests favorable to the native Hawaiian birds are in some areas without *Leiothrix*. A forest of this type at the Twin Craters (3,800 feet) in Hawaii National Park usually had not more than one individual per acre. Similar forests of the Upper Olaa Forest Reserve near a farming district exhibited a somewhat greater density.

On Maui in the Kipahulu Valley the virgin, undisturbed ohia lehua forests (elevation 4,000 to 6,000 feet and rainfall 250 to 350 inches a year) had very few birds of this species. In koa forests in this same valley, but between 2,000 and 4,000 feet elevation and with a rainfall of 150 to 250 inches a year, the population density of this species was slightly greater, an indication that the bird was generally present, but uncommon.

The birds are seldom seen more than 15 feet above the ground and then only when the ground cover is very thick, or when the birds are in heavy tree foliage. Only occasionally can they be observed in the higher strata of the ohia and koa trees. Most frequently the birds are heard in the low thickets and not seen. If one is quiet it is possible to observe the bird flitting from shrub to shrub next to the ground. These movements combine short fluttering flights and hops of a few inches.

## FLOCKING

We have seldom observed a flight of more than approximately 50 feet, but others report that flights of 200 feet are not uncommon in the more open parts of the range of the species. Longer flights are more frequently found during the winter, when the birds are banded together into traveling groups of 20 or even 100 birds. Some of the flocks in favorable places seem to confine their movements to a limited area, as at Kipuka Puaulu on Hawaii. However, some observers think the flocks represent groups migrating into the lowlands for the winter. There is a movement at this time, but it is more of a general diffusion into peripheral areas not heavily occupied during the breeding season, and it is by no means limited to downward movements, for, as mentioned previously, in winter the birds appear conspicuously in the ohia lehua forest of Mauna Loa at high elevations.

By May at Kipuka Puaulu the bands have broken up, and most of the birds are segregated by pairs. By late summer (July and August) small bands of 4 to 12 birds are common. Consequently, it appears that flocks are re-formed almost immediately after parental duties at the nest are completed. However, some of the birds remain in flocks throughout most of the breeding season (March through June).

## NESTING

Perhaps nesting occurs at all elevations found in the spring and summer range of *Leiothrix,* but on Oahu nests have been found only between 500 and 2,500 feet elevation. On Hawaii the highest elevation at which a nest was found was 6,100 feet at Kipuka Kulalio. Without exception on Oahu the nests have been less than 10 feet from the ground and located in the densest parts of the understory; one nest was only 18 inches above the ground. On Hawaii nests have been found from 3 to 7 feet from the ground. Choice of the nest site seems to depend not so much on the particular kind of vegetation as on its density, for nests on Oahu have been found in staghorn fern (*Dicranopteris linearis*), oi, palm foxtail, and guava, on the finer branches of low-growing hau trees, and attached to the stems of ti leaves. On Hawaii, sites selected for nests included dense shrubs (aalii, *Dodonaea viscosa;* pukeawe, *Styphelia Tameiameiae*), the branches of trees (mamani, *Sophora*

*chrysophylla*), and fronds of tree ferns (*Cibotium Chamissoi*).

Occupied nests have been found between March 3 and May 7 on Oahu, and from early March through June on Hawaii. It is likely, however, that further investigation on both islands would reveal a longer breeding period.

On March 3, 1945, a nest with four eggs was found at 1,200 feet on the west side of Manoa Valley, Oahu. A complete description of this nest follows, because we have been unable to find any published account of the nest of this species. The nest was located in a well-shaded spot beneath a koa tree and in a dense growth of the exotic palm foxtail. It was well concealed by the rank growth of the foxtail and would have passed unnoticed had not the bird flushed when the observer stopped some 18 inches from the nest, which was 36 inches from the ground.

Support for the nest was a fork near the terminal twigs of an oi shrub (*Stachytarpheta cayennensis*); the heaviest branch of the fork was only 2 mm. in diameter. The nest was attached to the fork by only a few fibers from the leaves of the foxtail, which were wound around the twigs and woven into the rim of the nest. While not swinging as free, for example, as the nest of an oriole, the nest was definitely pendulous.

The measurements of the outside of the top of the ovoid nest were 9 cm. by 11 cm.; corresponding dimensions of the inside were 4.5 cm. by 6 cm. Over-all depth of the nest was 8.5 cm., but the depth of the cavity was 5.5 cm. From these figures we may conclude that the walls of the nest vary between 2 and 3 cm. in thickness.

All materials used in constructing the nest came from one plant, the palm foxtail, which was available within a few inches of the nest site. On the outside, entire leaves (some 18 inches long and 1¼ inches wide) were loosely wrapped around the nest and tied into the nest by small fibers (fibrovascular bundles) from the leaves of the foxtail. However, the bulk of the nest was woven of longitudinally split leaves from which the epidermis and mesophyll had disappeared, leaving only 8 to 15 parallel fibers. The lining of the nest consisted of single fibers from the same plant; they were loosely laid in to form a springy inside surface for the nest. The only part of the nest not coming from the leaf of this grass was three rootlets (the largest was 25 cm. long and 1 mm. in diameter) woven into the rim of the nest. The rootlets gave additional rigidity to the free edge.

Because of certain differences in construction and in materials used it seems desirable to describe another nest, found May 18, 1940, at 6,100 feet at Kipuka Kulalio, Mauna Loa, Hawaii. It was suspended in an aalii tree from the crotch of a forked twig at a height of 6½ feet from the ground and was secured by grass stems bent over the arms of the crotch and incorporated into the wall of the nest. The outermost part of the nest was a sling of grass woven vertically from the rim on one side, under the nest, to the opposite rim. This was the sole support, as there was no base of twigs. Inside this sling, grass was woven in various directions to make up the wall, which was about 3 cm. thick. Grass was worked in horizontally along the rim. There was a lining of loosely woven grass, strands of which ran diagonally up the sides to bend down at the rim at angles of about 80° and run again across the floor of the nest. The whole structure was firm, but not compact. Light could be seen through the sides. A few leaves had been placed near the bottom and in the bottom. The materials in the nest were 85 per cent grass (60 per cent stems and 25 per cent leaves), 15 per cent leaves of aalii, a trace of rootlets in the rim, and a few feral goat hairs in the lining. Measurements of this nest were:

| | GREATEST DIAMETER | LEAST DIAMETER | DEPTH |
|---|---|---|---|
| | cm. | cm. | cm. |
| Outside | 11.5 | 9.0 | 9.0 |
| Inside | 5.5 | 4.5 | 5.5 |

## EGGS

The egg is shiny, with an extremely pale-blue ground color and a ring of red-brown or purple splotches around the larger end. A few pale-brown splotches are found on the blunt end and the sides of the egg, less often at the apex. Small brown specks and dark scrawlings may overlie the brown and purple splotches, especially at the blunt end.

Weights and measurements of eggs from two clutches are given below. The weights were taken 3 days before the eggs hatched.

| | WEIGHT | LENGTH | DIAMETER |
|---|---|---|---|
| | gm. | mm. | mm. |
| *Clutch 1* | | | |
| egg 1 | 2.4 | 20.9 | 16.5 |
| egg 2 | 2.4 | 20.3 | 16.4 |
| egg 3 | 3.0 | 21.3 | 16.5 |
| *Clutch 2* | | | |
| egg 1 | ... | 20.4 | 15.4 |
| egg 2 | ... | 20.3 | 15.5 |
| egg 3 | ... | 20.0 | 15.4 |
| egg 4 | ... | 20.9 | 15.6 |

The number of eggs observed in a clutch varied between two and four, with an average of about three (two nests with two eggs, two with three eggs, and three with four eggs).

## HATCHING

The earliest hatching observed on Hawaii was on March 14, and the latest was on June 16. On Oahu these dates were March 10 and May 15.

Cracks were found in all three eggs of a clutch at 3:00 P.M. on May 22. The cracks appeared to have resulted from activity inside the egg. In one egg the cracks were just distal to the largest diameter. A second egg had cracks in various places around its greatest circumference, while the third had only one small hole immediately distal to the greatest diameter. By 5:00 P.M. two of the eggs had hatched. The shells had been removed from the nest and could not be found on the ground; apparently they were carried away by the parent. By 5:35 P.M. the third egg had broken open. The shell was broken in a ring just proximal to the largest diameter. The crown of the embryo was pressed against the cap of the shell. The hatching bird flexed its neck and then extended it, shoving the shell cap forward and freeing its head. After resting a few moments it worked its legs back and forth twice, simultaneously kicking its body forward and the shell backward.

## DESCRIPTION AND DEVELOPMENT OF THE YOUNG

When the nestlings were 1 hour old they appeared as follows: skin, rich reddish apricot, except where feather follicles caused gray color as in humeral tract, dorsal surface of neck, upper part of wing, and mid-dorsal region, and over eye; bill, reddish apricot, except upper mandible (gray between nares and tip); egg tooth, whitish yellow; rictus, light yellowish apricot; legs and feet, apricot; claws, yellow. Down feathers were present above eye, along occiput and mid-dorsal line from interscapular region to posterior edge of oil gland.

When the young were 24 hours old the skin color was less reddish, and the gray feather tracts were more pronounced and extensive; plumules, absent in ventral tract; eyes, still closed and gray; legs, yellow-apricot; skin, loose in tibiofibular region and on neck, tight over belly; belly, more prominent and bulging than at hatching.

When the birds were 7 days of age the first primary feather was 15.5 mm. long and still within its sheath; bill, orange at edges, gray on ridge and side; rictus, whitish; legs, salmon.

When they were 11 days old the first primary was 33.5 mm. long and two thirds out of its sheath; central rectrices extended 3 mm. and 1 mm. out of their sheaths; plu-

mules, gone from back but present on crown and femoral tracts, sparse on crural tract; feathers forming fluffy covering over entire body. The primaries were lined with golden-yellow; breast, yellow-green; back, dark yellow-green; ventral tracts, whitish yellow-green; undercoverts of tail, yellow (still in sheaths); secondaries, black and dark green. The bill was dark salmon, but superficially gray; rictus, whitish along edge; legs, yellowish-tan; and claws, yellow-orange at tips.

The weights of the young are summarized:

| AGE | SIBLING A | SIBLING B | SIBLING C |
|---|---|---|---|
| | gm. | gm. | gm. |
| 1 day . . . | 3.1 | 3.0 | 3.2 |
| 7 days . . . | 13.0 | 13.9 | 13.5 |
| 11 days . . . | 15.0 | .... | 15.2 |

When the birds were 1 hour old, their movements were sluggish; the head was lifted to receive food, and swallowing was accomplished. When 24 hours old the nestlings could squirm around; they rested on their abdomens. They threw back their heads and opened their mouths frequently. Begging behavior and ejection of feces could be brought about by touching the nestling. When not active they lay curled up on their sides with legs and toes flexed. At 7 days of age they still were unable to crawl. At 11 days one sibling left the nest when the observer tipped it to look inside. It escaped into the bushes by moving along the ground in short flights (3 feet). The nestlings could perch well, and they shifted their footholds to compensate for movements of the nest. Low-pitched alarm notes were uttered when they were trying to escape capture.

### FOOD

Animal matter found in the stomachs of 13 birds from Hawaii National Park came from various species of Hymenoptera, Diptera, Lepidoptera, and Mollusca. Plant objects included fruits of the thimbleberry (*Rubus rosaefolius*) and other fruits and stems. The proportion of animal to plant matter varied from all animal to all plant food, but the proportions usually were between 40:60 and 60:40 by volume. Grit was typically present in the gizzard.

Observational data on Oahu indicate that the birds also feed on the fruits of strawberry guava (*Psidium Cattleianum*), overripe papayas, petals of small flowers, and small new buds of various plants. *Leiothrix* has also been seen to capture insects which flew near its position, but in feeding on insects it does not fly out from a perch in typical flycatcher fashion.

### BIRD MALARIA

Blood smears from 11 specimens of *Leiothrix* from Hawaii were examined by the U. S. Fish and Wildlife Service. *Plasmodium vaughani* was reported from one smear made from a bird taken near Kipuka Puaulu in Hawaii National Park.

### INTERACTION WITH OTHER ANIMALS

Although at times *Leiothrix* seems to be a noisy, aggressive bird, we found no antagonism toward other avian species except on one occasion. An observer was at a nest of the species, and under the stress of excitement one of the adults drove a foraging Olive-green Creeper (*Paroreomyza bairdi mana*) from the nest tree.

Except for the Hawaiian Hawk on the island of Hawaii, there is no evidence to indicate that other avian species molest *Leiothrix* in any way. Elsewhere in the Hawaiian Islands, the only possible predators on this species are mammalian—the rat, the mongoose, wild dogs and cats, and feral hogs—and these would exert pressure on the population by destroying eggs and young.

## REFERENCES

CAUM, EDWARD L. *The exotic birds of Hawaii.* Bernice P. Bishop Mus. Occas. Papers 10 (9), 55 p., 1933.

HENSHAW, HENRY W. Report of the Committee on the Introduction of Birds into the Hawaiian Islands. *Hawaii. Forester and Agr.* 8: 61–64, 1911.

# NOTES

## Recommendations of Pacific Science Conference, National Research Council

A NUMBER OF POLICIES for the co-ordinated development of scientific research in the Pacific were adopted by the Pacific Science Conference of the National Research Council, which met at the National Academy of Sciences, Washington, D. C., on June 6–8, 1946. More than one hundred members of the conference from various divisions met with a number of liaison members from the State Department, War Department, Army Air Forces, Navy Department, U. S. Coast Guard, Department of the Interior, Department of Agriculture, Department of Commerce, U. S. Commercial Company, U. S. Office of Education, U. S. Public Health Service, Smithsonian Institution, American Council of Learned Societies, American Council on Education, and Social Science Research Council. Special guests were invited from a number of foundations interested in Pacific research.

The general and specific recommendations adopted by the Council, given below, should be of interest to all persons and organizations concerned with the systematic and methodical advancement of scientific studies in this vast area.

### GENERAL RECOMMENDATIONS

1. *Declassification*

THAT this Conference strongly recommend that, insofar as practicable, all Pacific Island materials and information now the property of government agencies and organizations be declassified and made available to recognized scientific organizations in accordance with recommendations from the proposed Pacific Science Survey.

2. *Conservation*

THAT throughout the Pacific area every effort be made:

*a.* To protect and preserve areas, objects and living species of flora and fauna having scientific, historic, or aesthetic significance, through appropriate conservation legislation, including the establishment of national parks, nature monuments, and reserves.

*b.* To take necessary measures to insure the preservation of flora and fauna in their native environment.

*c.* To set aside certain wilderness areas that are to be maintained inviolate except for essential scientific studies.

*d.* To determine which species are in danger of extinction and to take special measures for their protection and preservation.

*e.* To avoid the deliberate introduction of exotics wherever indigenous fauna or flora will be endangered, and to keep records of the intentional and accidental introduction and spread of exotic forms of animal life.

*f.* To minimize accidental introductions, by more effective quarantine efforts.

*g.* To apply caution in the use of insecticides (such as DDT), rodenticides (such as 1080), herbicides, and other chemical controls of organisms, and to carry out thorough researches on the effects of such chemicals on all forms of life, including independent investigations before, during, and after the applications.

THAT conservation regulations and the importance of protecting vanishing species from extinction be brought to the immediate attention of the establishments of the Armed Forces to prevent indiscriminate shooting or other practices that might cause the extinction of vanishing species of flora and fauna.

3. *Fellowships*

THAT the continuing organization arrange for research fellowships at varying financial grades for competent graduate students, and for grants-in-aid to established scholars, including local inhabitants, in the several fields of science involved, as a part of the mechanics of staffing research.

THAT funds be made available to foster the interchange of information on the physiology, biochemistry, and biophysics of plants of importance in the Pacific area, to allow personal contact in this field between workers of various nationalities, and to make possible the translation and publication of research results obtained during the war in former enemy and enemy-occupied territories.

4. *The Pacific Foundation War Memorial*

THAT the Pacific Science Conference approve the concept of the Pacific Foundation: "Es-

tablished as a memorial to all those who served with the Armed Forces of the United States in the Pacific area." The purpose of this Foundation is to create a living war memorial devoted to the advancement of knowledge through research and conservation.

5. *Field Stations*

THAT scientific research base stations be established in Hawaii and Guam to work in close co-operation with existing research organizations and institutions in these areas.

THAT subsidiary stations be established in the following categories:

*a.* Floating stations consisting of vessels equipped for specific fields of research.

*b.* Advance base stations for both marine and terrestrial research on various types of islands and at the extremes of environmental conditions available.

*c.* Liaison stations to promote, in co-operation with allied agencies, research in the following areas: the Solomon Islands, Australian New Guinea, French Oceania, Indonesia, the Philippines, and the Galapagos.

THAT steps be taken toward the establishment of a base research station for various types of scientific investigation in the Galapagos Islands, making use of existing installations. This base should be of a permanent nature because of the importance of maintaining continuous oceanographic, biological, and meteorological records from this island outpost of South America. By way of specific illustrations of projects for this station, it may be pointed out that various elements of the land fauna are little known; that the extraordinary humid zone of the south face of the larger islands offers the opportunity for a unique ecological mountain transect, especially from Academy Bay or Indefatigable Island; that the more barren coasts and islands afford simplified ecological conditions, comparable to those of Arctic islands, and provide a veritable field laboratory in themselves; and that the biological interest of these islands is so great that conservation measures, under the control of such a research station, are urgently required.

6. *Science Appraisal*

THAT a survey be made of the state of our knowledge in the various fields of science in the Pacific. The appraisal would have for its main object the compilation of a guide to what has been done in these fields, including a bibliography of the basic contributions. As a result of the survey, an investigator would know where further research in any field is most needed. The publication resulting from the appraisal would be a guide for investigators and administrators. In addition, the guide would help in two specific kinds of important undertaking:

*a.* Conservation measures to be agreed upon by international action.

*b.* Commercial policies to be evolved in progressive steps as international agreements are made necessary by problems of the use and distribution of natural resources.

7. *Documentation Centers*

THAT documentation centers be set up at Washington and at Honolulu, some of their functions to be:

*a.* Distribution of bibliographies on special fields.

*b.* Maintenance of a clearing house on current researches and projects.

*c.* Publication of a list of American and foreign scientists (with addresses) who have active interest in the Pacific. This list should be cross-referenced as to:

(1) The islands or ocean areas with which each scientist has had first-hand experience.

(2) The specific fields in which each scientist is most qualified to furnish co-ordinating information.

(3) The fields in which each scientist may have become an authority even though he may not have visited or worked in the area.

*d.* Establishment of an archive of publications, translations, and manuscripts dealing with Pacific researches.

8. *Internships*

THAT internships on Navy Survey vessels be provided for one or more scientists, under the supervision of an experienced scientist, to gather scientific information and collections from all areas in which these vessels may operate.

9. *Pacific Congress*

THAT the projected Pacific Science Survey encourage and assist in the organization of the Seventh Pacific Science Congress as soon as possible, in order to further co-ordination of research already in progress or being planned and to perfect arrangement for co-operation among countries of the Pacific Basin.

10. *Check Lists of Flora and Fauna*

THAT distribution check lists of the different

animal and plant groups in Oceania be prepared and published.

11. *Descriptive Geography of Micronesia*
THAT a Descriptive Geography of Micronesia be compiled, covering land forms, floral and faunal ecology, and human geography. Wherever possible, fullest use should be made of visual presentation of data, including aerial photographs that have already been taken by Army and Navy Air Forces.

12. *Scientific Appraisal at Bikini*
THAT means be provided for continuation of the appraisal of biological consequences of the atomic bomb tests at Bikini, over a period sufficiently long to cover the repopulation of the waters and lands with plant and animal life.

13. *Specific Scientific Recommendations*
THAT every assistance be given to the implementation of the specific recommendations for scientific research formulated at the conference in the fields of the anthropological sciences, the earth sciences, oceanography and meteorology, the plant sciences, public health and medicine, and the zoological sciences.

## RECOMMENDATIONS PERTAINING TO INTERNATIONAL CO-OPERATION

1. THAT the Pacific Science Conference recognizes the urgency of international co-operation in scientific research and to that end recommends to the Congress of the United States that the Act of August 9, 1939, which authorizes the United States to co-operate with the American Republics in scientific undertakings of mutual interest, be amended to authorize such co-operation with all foreign countries.

2. THAT the governments of the countries of the Western Pacific be invited to consider the establishment of visitors' facilities at the principal centers where considerable research facilities for resident scientists already exist.

3. THAT a committee be appointed to investigate and recommend avenues of collaboration with the United Nations and other international organizations.

4. THAT the Pacific Science Conference urge the establishment, in co-operation with allied agencies, of liaison stations to promote research in the following areas: New Zealand, the Solomon Islands, Australian New Guinea, French Oceania, Indonesia, the Philippines, and the Galapagos.

5. THAT the proposed Pacific Science Survey:
   *a.* Collaborate with interested institutions and individuals, American and foreign, in the preparation of a series of regional floras. It is suggested that a beginning be made by drawing up plans for the publication of (1) a Flora of Micronesia and (2) a Flora of the Philippines, with a judicious amount of preliminary field work in both areas.
   *b.* Encourage field work looking toward publication of other regional floras in the Pacific and Oriental areas.

   THAT, to forward these objectives, requests from countries interested in securing American co-operation be welcomed in order to further the preparation of regional floras, which, in preliminary editions, may extend only to the genera.

   THAT field work be encouraged in those areas for which the data in hand are obviously inadequate, as, for example, the New Hebrides and the Solomon Islands.

6. THAT the Pacific Science Conference is highly gratified to learn of the establishment of the "Institut Francais d'Oceanie" and appreciates the opportunity afforded by the invitation of the French Government to American scientists to make use of the institute's facilities and to co-operate with French scientists in furthering knowledge of the Pacific area through a wide range of scientific research.

7. THAT encouragement be given (*a*) to the establishment by the government of the Netherlands Indies of a scientific research station at Hollandia, Dutch New Guinea, and (*b*) to the use of former Army installations for this purpose. The location of a scientific field station at Hollandia would greatly facilitate the scientific exploration of many parts of New Guinea. It is recommended that, if established, the station be provided with a small vessel suitable for coastwise operations and, if possible, plane facilities. American scientists would welcome an invitation to utilize the facilities of such a station and to co-operate with scientists working there.

8. THAT the survey of the algae and algal resources of Philippine and Indonesian waters, begun before the war by collaboration with Philippine and Dutch scientists and institutions, be continued and be extended to cover the Pacific by drawing into collaboration all agencies and persons willing to contribute toward this end. The food and fertilizer values of algae, and also their value as raw

materials in the preparation of commercial products, should be appraised.

9. THAT international correlation and standardization of nomenclature and of methods of measurement be established by international committees representing all nations working in the general Pacific area. (This relates particularly to land forms, rock and soil types, geological timetables, etc.)

10. THAT the Pacific Science Conference go on record as expressing its recognition of the urgent need for support in the rehabilitation of scientific libraries and scientific collections destroyed during the war.

11. THAT in the Philippines a scientific center supported by private funds be established as an aid to scientific work and studies. Such a center should co-ordinate its activities with existing government bureaus and institutions.

## SPECIFIC RECOMMENDATIONS

A co-ordinated program of scientific research for the Pacific Islands (under American or foreign administration) has been formulated. Recommendations are as follows:

### I. *DIVISION OF ANTHROPOLOGICAL SCIENCES.*

*General preamble.* It is recommended that this Conference, in collaboration with local inhabitants, encourage investigation of problems concerning the welfare of the people of the Pacific Islands.

A. *General studies* that should be stressed include:
   1. A comprehensive anthropological survey, covering each of the major divisions of the subject, priority to be given to an ethnographic study of Micronesia.
   2. Human geography.
   3. A survey of Micronesian linguistics and the establishment of standards of phonetic transcription, with the publication of textbooks of native languages.
   4. A survey of the social, economic, and political structure of the present-day cultures of Micronesia.
   5. Intensive study of the effects upon Micronesian societies of non-indigenous contact, such as Spanish, German, Japanese, and American culture, as well as of alien civil administration.
   6. Survey of Micronesian nutrition, diet, dietary therapeutics, food habits, and production and preparation of food.

B. *Specific studies* that should be initiated as soon as possible include:
   1. A physical anthropological survey of the Micronesians.
   2. Problems arising from increase and decrease of population.
   3. Child growth and development.
   4. Race mixture.
   5. Land utilization in Micronesia, to be studied with a view to determining those areas best suited for indigenous food crops and those best suited for commercial crops.
   6. Systems of land tenure, fishing rights, and property concepts in Micronesian cultures.
   7. Cultural conditioning (including the effects of the school system) of the child from infancy to maturity, to be studied in significant Pacific areas by anthropologists, psychologists, and educators.
   8. Native trade, and methods of developing natural resources.

### II. *DIVISION OF EARTH SCIENCES.*

A. *Scope.* The Earth Sciences as herein defined include Physical Geography, Geology, and Geophysics.

B. *Regions of interest.* It is recommended that this Conference encourage a research program in the Earth Sciences for the entire Pacific Basin, with particular emphasis on Micronesia.

C. *Recommended Investigations.*
   1. *Geology.* Systematic geological surveys and areal geological mapping of selected key islands and, later, of island groups in the Pacific as a basis for scientific researches in paleontology, stratigraphy, petrology, and physiography; terrain studies and engineering-geologic interpretations of water supplies, construction materials, foundation conditions, mineral resources, and soil types.
   2. *Soil Science.* Reconnaissance soil surveys of the whole Pacific area and detailed soil surveys of regions of agricultural importance, including research through field stations and field working parties for each of the principal soil types as to:
      *a.* Genetic formation in relation to environment.
      *b.* Mechanical properties in relation to engineering needs.
      *c.* Crop adaptability and response to irrigation and fertilization in relation to production, nutrition, conservation, flood control, and land use.
   3. *Agricultural Committee.* Appointment of a Committee or Division on Agriculture under the Pacific Science Survey, to assist administrators of islands in the coordination of action programs designed (*a*) to increase food production and im-

prove efficiency in growing all agricultural and forest products, whether intended as food or as industrial raw materials for local industries and for commerce, and (*b*) to conserve soils, waters, and forests.

4. *Gravity Investigations.* Gravity observations at several atolls and at selected points about the shores of the lands and islands of the Pacific. It is recommended that a U. S. Navy submarine, using Vening-Meinesz pendulum apparatus, be employed for one year to make gravity observations at sea, particularly in the vicinity of the Aleutian trench and other trenches. These observations are intended to increase knowledge of geological structure, of seismological conditions, and of deflections of the vertical.
5. *Precise Position Determinations.* Employment of all possible means to improve the quality of basic astronomic position determinations and extend first-order triangulation when feasible, in order to obtain better basic geographic positions for airports and for Loran and other navigational installations and for general aerial mapping.
6. *Seismology.* Establishment and permanent maintenance of four additional seismological stations containing modern seismographs at selected points in the western Pacific, to improve the science of locating and studying Pacific area earthquakes, to increase knowledge of the geologic structure of the area, to study the relations between earthquakes and seismic sea waves, and to evaluate earthquake and seismic hazards.
7. *Microseisms.* Additional study of extratropical meteorological disturbances in the north Pacific and Alaska area, through extending to the Aleutian Island area the observation and study of microseisms and their relation to meteorology.
8. *Seismic Prospecting.* Promotion of seismic prospecting work about the submarine trench areas and at selected points about the shores and in the depths of the Pacific, for determination of sediment depths and of underlying rock structure.
9. *Structure of Atolls.* Investigation of the structure of typical atolls, including submerged, atoll-like structures, by seismic prospecting and core drilling, magnetometer prospecting, gravitational prospecting, and detailed bathymetric surveys of their flanks and approaches.
10. *Volcanology.* Descriptive geological and geophysical observations of various types at a number of active volcanoes, particularly any volcano showing unusual activity. Modern seismic, gravimetric, electric, and magnetometric techniques should be applied to the determination of underground structure in volcanic regions.
11. *Physics of the Ionosphere and Troposphere.* Investigation of atmospheric factors influencing the propagation of electromagnetic radiation at all frequencies, in relation to radio communication and geomagnetism and to telemetering and tracking at extreme altitudes.
12. *Geomagnetism.* Establishment and maintenance of permanent magnetic observatories in the Aleutians, in the Philippines, at Samoa, and at Christmas Island or Jarvis Island, for continuous recording of magnetic variations; employment of two field magnetometer parties for one year to investigate magnetic conditions at islands and along the shores of the Pacific, and complete repetition of such investigation after an interval of five years.

    Suitable airborne magnetic instruments should be utilized and further improved as necessary for investigations generally over the Pacific Ocean area, and two planes so equipped should be employed for one year in general magnetic work. These studies are designed to improve nautical and aeronautical charts, to investigate magnetic anomalies as related to geologic structure and volcanism, and to achieve other scientific results.
13. *Hydrology.* Investigation of infiltration of rainfall, stream flow and run-off, and flood hazards, and preparation of isohyetal maps; investigation of storage and diversion for irrigation and hydroelectric power development, and of ground water resources; and research in dynamics of erosion.
14. *Mineral Industries.* Initiation of prospecting operations to evaluate the importance of mineral deposits in the local economy, as the information on these deposits becomes available from geological studies.
15. *Mapping Activities.* It is recommended that hydrographic, topographic, geophysical, and submarine contour mapping be supported and correlated.
16. *Geologic Timetable.* Gradual establishment of a standard stratigraphic sequence of geologic formations in the Pacific. In order to understand the succession of geologic events in the area, a geologic timetable correlating the rock formations of the islands with those of the surrounding mainlands is essential.

III. *DIVISION OF OCEANOGRAPHY AND METEOROLOGY.*

The Division recommends:

A. THAT the United States immediately initiate preparations for a comprehensive program of investigations in the marine sciences in the Pacific area and that the following topics be a part of the general program of investigation.

1. *Currents.*
   *a.* The vertical, horizontal, and seasonal distribution of tidal and non-tidal currents.
2. *Interrelations of Sea and Atmosphere.*
   *a.* Data on waves: height, length, and period, including frequency and direction of waves of different magnitudes by months.
   *b.* Heat exchange with atmosphere.
   *c.* Water exchange with atmosphere.
3. *Distribution of Physical Properties.*
   *a.* Complete survey, by areas and seasons, of temperature and salinity in the ocean, the variability of these characteristics, and the factors affecting this variability.
   *b.* Transparency of sea water and how it is affected by seasonal variations in coastal waters.
4. *Distribution of Chemical Properties.*
5. *Characteristics of Sea Bottom.*
   *a.* Composition, firmness, color, and geological character of bottom sediments, in offshore areas, channels, and harbor mouths.
   *b.* Beaches and wave zone, including trafficability characteristics of beaches and shallow water (hardness, cohesiveness, mechanical composition, and bearing capacity).
   *c.* Harbor and coastal silting and erosion resulting from waves and currents.

B. THAT the co-operative tidal program now in operation by the Coast and Geodetic Survey be continued and expanded in the western Pacific until observations are obtained over a sufficient period of time for a satisfactory analysis of the Pacific tides.

C. THAT support be given to the maintenance and expansion of the network of meteorological surface and upper-air stations in the Pacific area, including weather reconnaissance squadrons and special stations set up for the purpose of observing sferics, microseisms, sea swell, and radar as these relate to weather. The program would include:

1. Study of medium and high altitude meteorology (above 5,000 feet), particularly of the northern and western areas.
2. Basic theoretical work on the cause and maintenance of fog and a synoptic and geographic study of the distribution of fog in the North Pacific.
3. Study of the thermal, moisture, and wind micro-structure of the lower layer of atmosphere (less than 5,000 feet).
4. Research in formation, structure, and motion of typhoons.
5. Study of meteorological conditions causing anomalous propagation of ultra-high-frequency radio and radar in the western Pacific area.

D. THAT support be given to the establishment of an office to supply information regarding locations of meteorological stations and available meteorological observations, and to furnish meteorological advice to agencies or individuals planning scientific research projects in the Pacific area.

E. THAT, if expeditions are organized in the Pacific area, provision be made for taking detailed sea-surface, meteorological, and radiation observations that are necessary to investigate the energy exchange between ocean and atmosphere and to study other problems.

F. THAT, since the already available data from the Pacific area must be thoroughly studied, analyzed, and evaluated before a comprehensive and well-integrated program in oceanography (marine sciences) can be decided upon:

1. An office be established under the National Research Council to study, analyze, and evaluate the data and make the results available to the planning group.
2. This office be adequately staffed by a head scientist and necessary clerical and technical assistants.

G. THAT, because of the different requirements in the various areas and in the several fields of science, four vessels be procured, equipped, and operated for general investigations on the high seas and that eight vessels be procured, equipped, and operated for regional investigations. One of the four large vessels and the eight smaller vessels should be used primarily for research in the natural resources of the sea and, in addition, should be equipped to participate in general oceanographic studies conducted by means of the other three large ships.

IV. *DIVISION OF PLANT SCIENCES.*

A. WHEREAS there has been a lack of correlation among the botanical endeavors of scientists of different countries, and

WHEREAS the most rapid progress and scientific co-operation among these countries in the study of botanical problems of the Pa-

cific will be brought about by personal contacts,

*Be it resolved* that botanical missions be sent to Japan, China (especially Formosa), and Korea (1) to obtain specimens, photographs of type and other important specimens, publications, translations of publications, and manuscripts, (2) to ascertain the needs of Pacific and Oriental botanists for corresponding scientific materials from America, and (3) to arrange for co-operation among the scientists of the participating countries.

B. WHEREAS ethnobotanical investigations are frequently neglected by both botanists and anthropologists, and

WHEREAS the field of ethnobotany is one in which much useful research may be done by workers in other fields,

*Be it resolved* that the National Research Council recommend methods of securing comparable linguistic terminology on economic botany and primitive agriculture from the boundaries of India through Polynesia.

C. WHEREAS the experiment station of the South Seas Bureau of the Japanese Government at Kolonia, Ponape, has a large collection of economic plants, two large modern buildings, and many acres of tillable land, and

WHEREAS both wet land and well-drained land have been under active cultivation, and the area is well suited for experiment station work,

*Be it resolved* that agricultural experimentation be continued at this station.

D. WHEREAS the food production capacity of many Pacific Islands might be increased by judicious enrichment of the flora through plant introduction, and

WHEREAS many other products of utility might be made available to isolated peoples,

*Be it resolved* that measures be taken to introduce widely throughout the Pacific new, useful, disease-free plants (including forest trees), favoring those that may have two or more utilities, such as use for lumber, for food, for fiber, for tannin.

E. WHEREAS modern modes of transportation and increased contacts of the island groups of the Pacific with each other and with the continents are greatly increasing the danger of spread of plant diseases,

*Be it resolved* that, whenever possible, a survey of parasitic fungi and other disease-producing organisms be made a part of plant science projects sponsored in the Pacific area, and

*Be it further resolved* that every precaution be observed to prevent the spread of diseases and pests (including weeds). Increased attention should be given to quarantine regulations and renewed studies should be made of the efficacy of quarantine measures.

F. WHEREAS certain problems of marine biology are of practical significance in the operation of ships,

*Be it resolved* that the following studies be undertaken:

1. Biological study of the distribution and habits of marine fouling organisms.
2. Investigation of the distribution and causes of phosphorescent waters.
3. Survey of fouling in certain areas of importance to shipping in order to determine maximum depth of significant marine growth.
4. Survey in representative areas of the main marine growth forms, their seasons of attachment and rates of growth.
5. Distribution of kelp and other large algae.

## V. *DIVISION OF PUBLIC HEALTH AND MEDICINE.*

The Division recommends: THAT co-operative studies be conducted by qualified workers in the field of medicine, together with workers in the allied sciences, as follows:

1. Problems of the Pacific that have been demonstrated to be of particular importance to "non-immune whites."
   - *a.* Diseases particularly prevalent in the Pacific and of major importance: dysenteries, malaria, hepatitis, dengue complex, and tropical dermatitis; also diseases of lesser but peculiar importance: scrub typhus, schistosomiasis, filariasis, and Japanese B encephalitis.
   - *b.* Dissemination and implantation of disease, with particular reference to quarantine procedures.
   - *c.* Possible deleterious effects of the widespread use of DDT.
   - *d.* Utilization of special opportunities that may arise in the study of respiratory diseases.
   - *e.* Determination of factors that have led to the absence of arteriosclerosis and hypertension, which are presumed to be largely or entirely absent in certain native population groups of the Pacific.
   - *f.* Nutritional problems that arise from residence in the tropics.

2. Problems that have been demonstrated to be of particular importance to native populations.
   *a.* Diseases of special importance to natives, such as tuberculosis, yaws, malaria, leprosy, and helminthiases.
   *b.* Medical education for native doctors and nurses of the area.
   *c.* Feasibility of instituting modern public health procedures in certain native groups.
   *d.* Native nutrition.

VI. *DIVISION OF ZOOLOGICAL SCIENCES.*

*General preamble.* It is proposed that this conference aid and stimulate a broad basic program of zoological collecting in, and a study of, the land and water areas that fall within its scope. To this end it is recommended:

1. THAT a "clearing house" be established to assemble data on unstudied scientific materials from the Pacific; that such materials and specimens be located and listed as to scope, place, time of collection, and collector; that such information be made available to all interested scientists; that staff and funds be secured for the organization, study, and identification of existing Pacific collections and for the preparation of reports, such staff and funds to be used to strengthen the appropriate departments of existing institutions.
2. THAT special attention be given to the survey of the fish life of the Pacific, including:
   *a.* Preparation of a bibliography of the entire Indo-Pacific fauna.
   *b.* Collection of specimens in all parts of Oceania.
   *c.* Revisions of the fauna, group by group, at several institutions.
   *d.* Preparation and publication of a check list and successive revisions.
3. THAT the governments of the Philippines, of Canada, of the United States (especially in the Territory of Hawaii and the States of Washington, Oregon, and California), and other countries concerned, be encouraged to:
   *a.* Undertake a thorough, closely integrated investigation of the tuna-like fishes of the tropical Pacific.
   *b.* Co-ordinate their research with the needs of the industry.
4. THAT researches be conducted on the reef and lagoon fisheries of the Micronesian Islands and that the products of these fisheries be allocated for native use.
5. THAT a vessel and crew be furnished to facilitate a survey of the fishes and mollusks of the Carolines.
6. THAT advanced studies of evolution be supported by the establishment of adequate laboratory facilities in the Hawaiian Islands, where advantage can be taken of the unique development of *Drosophila* and of other animals and plants in that area, which may yield data of utmost importance bearing on the evolution of living organisms.
7. THAT the zoological survey of the Pacific area be implemented by the provision of funds for permanent staff and visiting fellows to utilize the facilities of the biological stations proposed.
8. THAT the zoological work of shore and floating biological stations relating to the marine fauna be co-ordinated with biological oceanographic work undertaken as part of the total survey of the Pacific envisaged.
9. THAT investigations in animal husbandry in the Pacific region be undertaken to cover:
   *a.* Determination of existing livestock populations, including adaptabilities.
   *b.* Possible improvement of livestock production by the use of better adapted breeds and improved species, such as Indian cattle.
   *c.* Study of existing livestock diseases and parasites on the islands.
10. THAT early and continued attention be given to the following biological problems:
    *a.*[1] Comprehensive investigations of the zooplankton.
    *b.*[1] Determination of causes and seasonal variation of phosphorescent waters.
    *c.*[1] Analysis of the character and prevalence of background noises of animal origin. This will involve studies of (1) sound production, and (2) geographical and seasonal distribution of sound-producing animals and their ecological relationships.
    *d.* Regional studies on the biology of fouling and boring organisms.
    *e.* Researches on the biology of reef-building corals, with particular reference to composition of populations and to growth rates in different areas.
    *f.* Ecological studies of poisonous and otherwise dangerous animals.
    *g.* Ecological studies of termites.
    *h.* Survey of the populations and major breeding grounds of the larger marine birds.

[1] This should be correlated with other researches and programs in physical oceanography and fisheries biology.

# Micronesian Expedition of University of Hawaii, Summer of 1946

INTENSIVE FIELD RESEARCH in several branches of natural science was carried on in the islands of Micronesia during the summer of 1946 by groups of University of Hawaii faculty members. Based on a reconnaissance made by a team of four professors in this region in December, 1945, the summer program initiated research in this oceanic area, which has long been closed to most American scientists. The University of Hawaii surveys were planned and carried out through its Pacific Islands Research Committee, headed by Dean Paul S. Bachman. Transportation, housing, and other facilities were furnished by the thoroughgoing co-operation of United States Navy officials.

Most of the scientific investigations in Micronesia have been made by the Germans and Japanese, under which nations the islands have been administered for the past half century; and these studies, some of which still have value, were published in the German or Japanese languages. Much investigation, however, still remains to be carried on in fields that have not been touched or have been treated inadequately. With the likelihood that these islands will continue for some time under the control of the United States, it appears obvious that new and full information, reported in English, will be urgently demanded. The University of Hawaii, the American university closest to Micronesia, is in an advantageous position geographically, and from it other studies of the islands will be launched and continued in the future. Its faculty includes men who by training, experience, and interest are well fitted to carry on these studies; many of these men have already done field work on other Pacific islands. The administration, moreover, has recently filled positions with other men who have particular qualifications for conducting studies in this area.

A scientific study of Micronesia has important practical values. The published findings will contribute to a better acquaintance with these territories newly under American protection and to an understanding of the clash of cultures in these scattered islands—traditionally steppingstones in the oceanic travel lanes between Asia and the middle Pacific; and these findings will provide a storehouse of scientific knowledge to be drawn upon by workers in many fields. Information is needed at once if the United States is to carry on a policy of developing the government, education, and economy of the Caroline, Marianas, and Marshall groups.

A summary of the field work sponsored by the University in the several branches of natural science during the summer of 1946 here follows.

## BOTANY

A party consisting of Dr. Harold St. John, chairman of the Department of Botany, Dr. Donald P. Rogers, assistant professor of botany, and Richard S. Cowan, graduate assistant in botany, left Pearl Harbor on August 7 on LSM 382, a vessel which served as their base for most of the trip. In this Navy ship they surveyed the islands of Kwajalein, Likiep, Ailuk, Utirik, Mejit, and Wotje; thereafter they visited by seaplane the islands of Namu, Jaluit, Ailinglapalap, and Ebon. (Part of the route was planned to avoid duplicating efforts of scientists visiting Bikini on Operation Crossroads.) They returned on September 12 by air from Kwajalein, headquarters of the military government of the Marshall group.

One purpose of the trip was to make a general botanical exploration of as many of the Marshall atolls as was possible in the available time. Though these islands do not possess a large flora, they are little known because of their remoteness. Special attention was given by the University team to the ethnobotany of the crops of the natives; this subject, often neglected by the agriculturist and the botanical seeker of new species, might well reveal facts on the origins of certain crops, and studied in collaboration with qualified anthropologists might give new evidence on the migration routes of Micronesian and Polynesian native groups.

One to four days were spent on each of the islands studied, a time sufficient for a satisfactory initial exploration. In recent years, it was found, most of the islands have been turned into copra plantations, but all species of the higher plants reported by Chamisso in 1817 were found except one; these native plants were found fringing the seashore or sprouting in the coconut plantations. One of the most prominent of native trees is the pandanus—called "bop" by the Marshallese, who distinguish by name at least 20 varieties. A number of observations were made of driftwood logs found on island shores; several of these were apparently from trees native to northwestern United States. Study of these drift logs should give data on ocean currents and on the spread of certain plants in the Pacific.

An obvious gap in botanical knowledge of the Pacific is found in the lack of collections of fungi, algae, lichens, and bryophytes. Except for certain parasitic families which have been studied in Hawaii, the fungi of the main Pacific area are quite unknown. Identification of the forms collected should be a welcome contribution to mycology and should eventually add to present knowledge of distribution patterns of Pacific fungi and perhaps raise new problems in comparative morphology. For algae the region has been almost equally *terra incognita,* and the bryophytes and lichens, except those of Hawaii, have not previously been collected. The results of the summer expedition should eventually lead to the publication of several studies on the fungi and other cryptogams of the Marshall Islands.

Some 625 collections of higher plants and 500 of lower plants were brought back for further study at the University. These specimens will eventually be placed in the Bishop Museum for permanent record. Many photographs from the islands, both black and white pictures and color, were taken, as well as a number of 8-mm. motion picture films.

## ZOOLOGY AND BACTERIOLOGY

A party consisting of Dr. Robert Hiatt, chairman of the Department of Zoology and Entomology, Dr. Harvey I. Fisher, assistant professor of zoology, Dr. Floyd W. Hartmann, acting chairman of the Department of Bacteriology, and two assistants, Leo Fortess and Eveni Levi, left by air from Honolulu on July 17, and after a 5-day stay at Guam, went to the island of Yap by LCI. After a stay of almost a month, they left Yap on August 22 by air and returned, via Saipan and Guam, to Honolulu on August 28. Dr. Fisher collected vertebrate specimens and Dr. Hiatt collected invertebrate specimens.

The ornithology, mammalogy, and herpetology of the Micronesian chain have been virtually unknown to English-speaking students. Study of the vertebrate fauna in this area is of interest from the viewpoints of taxonomy, distribution, and natural history, because detailed studies are available for certain surrounding regions. One purpose of the survey was to note the movement of bird species from the Asiatic continent southward and also eastward into the Palaus and the Marianas chain, as well as movement northward within this chain; in other words, to compare the avifauna of Yap with that of Peleliu and Guam. A complete zoological exploration of the Yap islands was made. About 150 skins of birds and mammals and some 50 alcoholic and skeletal specimens were brought back for further study. In addition, a number of reptiles were collected. It is hoped that present investigations may demonstrate means of saving from extinction some of the particular endemic vertebrate species now isolated on small groups of islands or on individual islands; certainly the work will provide much new material for studies in morphology, natural history, ecology, and distribution.

No comprehensive survey of the invertebrate fauna of the Pacific islands formerly mandated to Japan has previously been made; indeed, the distribution of species west of Hawaii is virtually unknown. Studies of the specimens collected will provide information concerning the taxonomy, ecology, and distribution of these invertebrates. Thousands of marine invertebrates were collected and placed in preservatives for shipment to the University for further examination. Subtidal areas were explored with the aid of "skin" diving and "self-contained" diving techniques. The aim in exploring Pacific invertebrate life was not merely to identify and map the distribution of invertebrates in the Yap group, but also to compare these results with the dispersal of species previously known to exist in the Philippine and Indo-China area to the west and with that of species from the Great Barrier Reef of Australia to the south. Such studies might reveal the main routes of dispersal of species from the Asiatic mainland east into the Pacific. It is expected that future explorations will concentrate on island groups lying between Yap and the Hawaiian Islands.

Dr. Hartmann, in addition to collecting a number of autopsy specimens from rats in co-operation with Dr. Alicata on a study of the incidence of leptospirosis in the Carolines (see next section), carried on research on dental caries among the school children of Yap. Duplicate saliva specimens for several hundred children whose physical examinations and dental records were made available by Navy personnel were submitted to bacteriological examination. The Yap leper colony was visited, and observations were there made on administration, sanitation problems, and progress in rebuilding dwellings. A number of important bacteriological problems present themselves in the Caroline Islands, and these problems will have to be faced by the new American administration.

A large number of black and white photographs, as well as 200 colored 35-mm. slides and 2,000 feet of 16-mm. color motion pictures, were brought back as records of the 6-week visit to Micronesia.

## PARASITOLOGY

Dr. Joseph E. Alicata, head of the Department of Parasitology, University of Hawaii Agricultural Experiment Station, left by air on July 18 on a visit to Truk and Ponape in the eastern Carolines, and returned August 31.

Parasitic diseases are of paramount concern in the Pacific area and are responsible for retardation in the development of island areas and in the

expansion of the livestock industry. Although scattered reports are available on the occurrence of parasitic diseases of man in Micronesia, very little is known about their actual prevalence; nor is much known about parasites which affect domestic animals. Information acquired through the present study and similar explorations planned for the future should assist in the adoption of more adequate health measures for man and, through parasite control, improved quality and quantity of animal products. The geography of parasitic diseases of the Pacific area and the factors responsible for the spread of such diseases need much investigation in order to formulate intelligent control measures.

The major purpose of the trip was to collect ectoparasites and endoparasites of economically important animals such as cattle, swine, and poultry, and to investigate the possible occurrence of murine leptospirosis or Weil's disease in Micronesia. Data collected in the Hawaiian Islands indicated that this disease might be widespread in the Pacific area where rainfall is usually high and rodents (the agency which usually transmits the disease) are abundant. A number of rodents were trapped in the Caroline Islands. Examination of kidney samples from these rodents for leptospirae will provide a basis for better judgment on the recognition and control of this disease in man. Dr. Alicata also carried on a study of the incidence of helminthic infection among the natives of Ponape and Truk. He experimented as well with the use of copper sulfate preparations for control of the giant land snails which destroy much island vegetation.

## Survey of Micronesia by U. S. Commercial Company, 1946

An economic survey of Micronesia by 25 specialists attached to the U. S. Commercial Company was completed in the autumn of 1946. It was carried out primarily to discover how fully these formerly Japanese-mandated islands could be developed to promote the welfare of the native populations.

A comprehensive report is in preparation for the benefit of government agencies and others concerned. It is expected that this will contain factual data of value in determining future policies with reference to the islands, particularly as regards the fostering of a self-sustaining native economy and the avoiding of commercial exploitation.

Teams of scientists were assigned to remain in the various areas for a minimum of 3 months of observation. In addition to six area economists, specialists on the study included botanists, horticulturists, agronomists, animal husbandry specialists, entomologists, soils experts, nutritionists, mineral geologists, water geologists, fish specialists, and specialists in handicrafts.

An LCI, made available by the Navy, carried the several specialists from island to island throughout Micronesia, and in port served them as a floating laboratory and base of operations. This vessel returned to Honolulu at the end of the survey, carrying specimens, records, and samples of native-made products. Many of these latter will find their way into the collection of the Bishop Museum.

The study was carried on originally under the direction of Dr. Douglas L. Oliver, who retired in September as head of the agency for the Middle Pacific. At present the work is headed by Richard B. Black, former expedition director.